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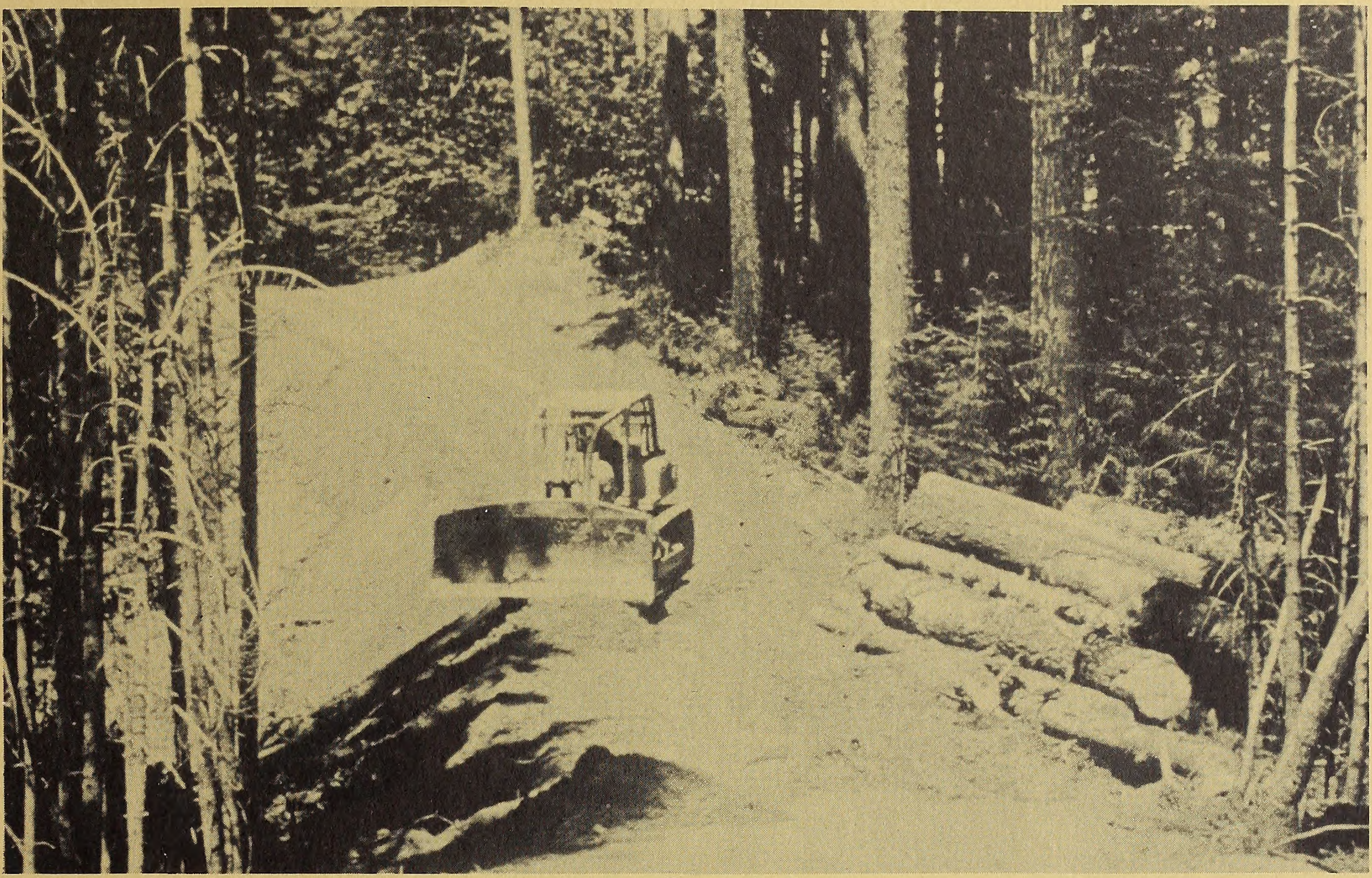
GUIDE TO REDUCE ROAD FAILURES IN WESTERN OREGON



by

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August 1973

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INTRODUCTION

There is no question that road construction is an extremely important activity in western Oregon. Many thousands of man hours are expended each year to locate, design, construct and maintain road systems. The construction of stable roads can sometimes be difficult because of the steep terrain, weak geologic material, and the heavy winter rainfall that is common to western Oregon. Road failures can exert a tremendous impact on natural resources and can cause serious economic losses. Road failures have blocked streams, destroyed bridges, ruined spawning sites, lowered the productivity of forest lands and damaged private property. It is vital that those personnel engaged in road building activities be aware of the basic principles of slope stability and understand how these principles can be used together with various geologic materials and specific conditions of slope and soil to construct stable roads.

This training guide presents a general outline of the geology of western Oregon to provide a background for discussion of specific problems of road construction. Basic slope stability is illustrated by a description of the balance of forces that exists in undisturbed slopes, how these forces change as the road is constructed, and how ground water affects slope instability and can cause road failures. The final section of this guide discusses techniques for constructing stable roads on specific geologic materials and soils. These techniques represent a summary of the knowledge of engineers, foresters, geologists, and soil scientists from the Bureau of Land Management, Forest Service, Soil Conservation Service, private industry and the universities. The techniques presented here are not meant to be the ultimate in technology but merely the "state of the art" at this time. The districts are encouraged

to revise and add to these techniques for construction of stable roads as the level of our experience improves. Finally this training guide, if kept up to date, can provide an introduction to stable road construction for new employees or transferrees.

GEOLOGY OF WESTERN OREGON

Western Oregon has a complex geologic history of volcanic activity, deposition of thick beds of sedimentary material, and more volcanic activity with erosion operating continuously at varying rates. Western Oregon can be subdivided into four physiographic provinces (Figure 1) that illustrate this varied geologic history: the Western Cascades, the Coast Range, the Klamath Mountains, and the Willamette Valley. The Willamette Valley will be excluded from any further consideration because road construction within the valley entails only a slight risk of slope failure.

The wide variety of geologic materials present in western Oregon can be separated into major groups (Figure 2), each with particular characteristics that affect road location, design, construction, and maintenance. When Figures 1 and 2 are compared it is seen that the Coast Range is composed mostly of bedded sediments with scattered volcanic material. The Western Cascade province is composed mostly of volcanic material with small isolated areas of bedded sediments and granitic rock. The Klamath Mountain province is the most geologically complex with very old sedimentary and volcanic rocks, locally metamorphosed (altered by heat and pressure), and intrusions of granite and serpentine.

It should be emphasized that the simple description of the geology of western Oregon that follows has several purposes: it illustrates the variety and regional variability of geologic materials; it introduces basic terms and concepts in geology; and, finally, it provides a background for the interpretation of detailed geologic maps that may be consulted for a specific project.

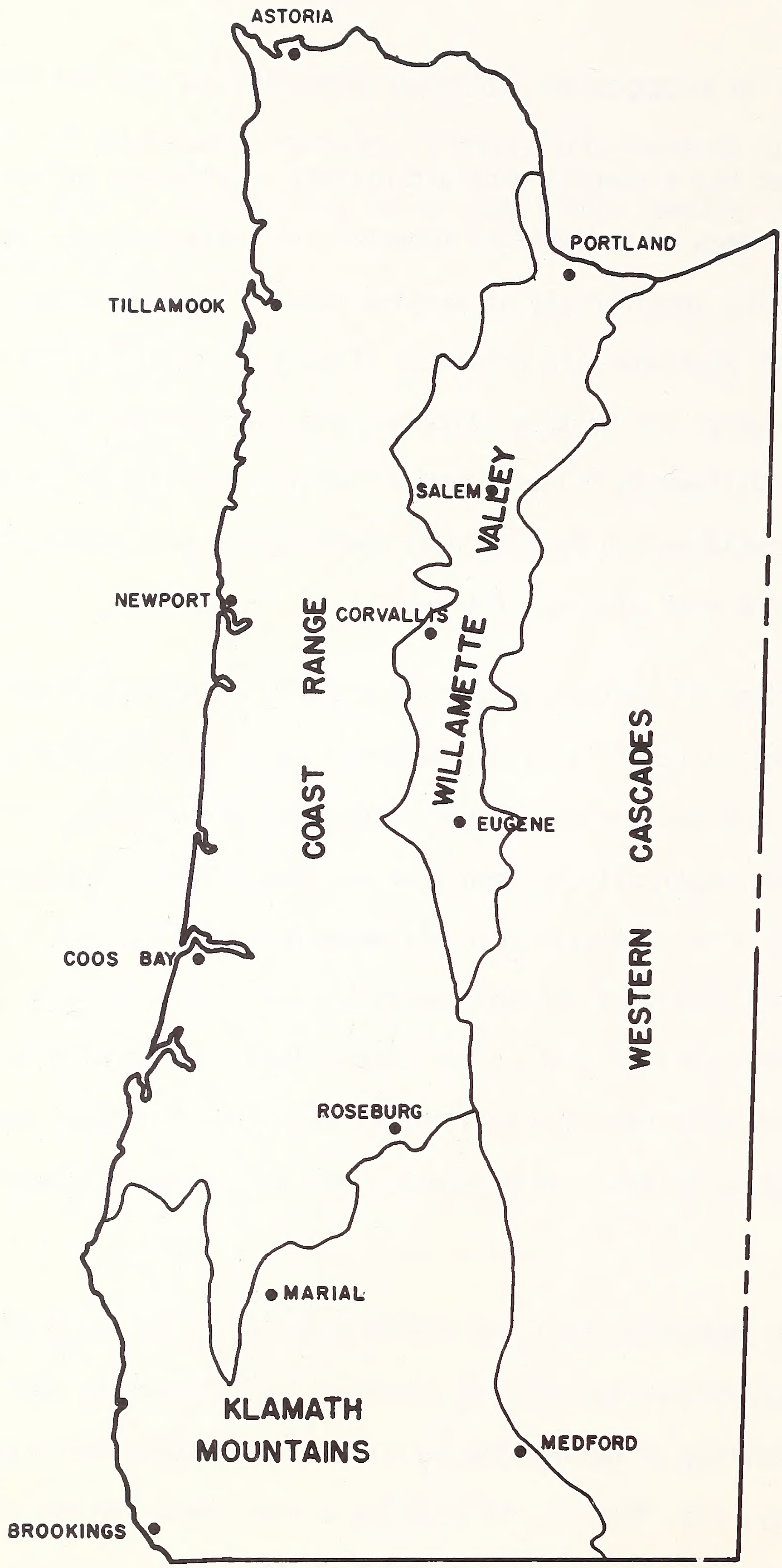


FIGURE 1 – PHYSIOGRAPHIC PROVINCES OF WESTERN OREGON

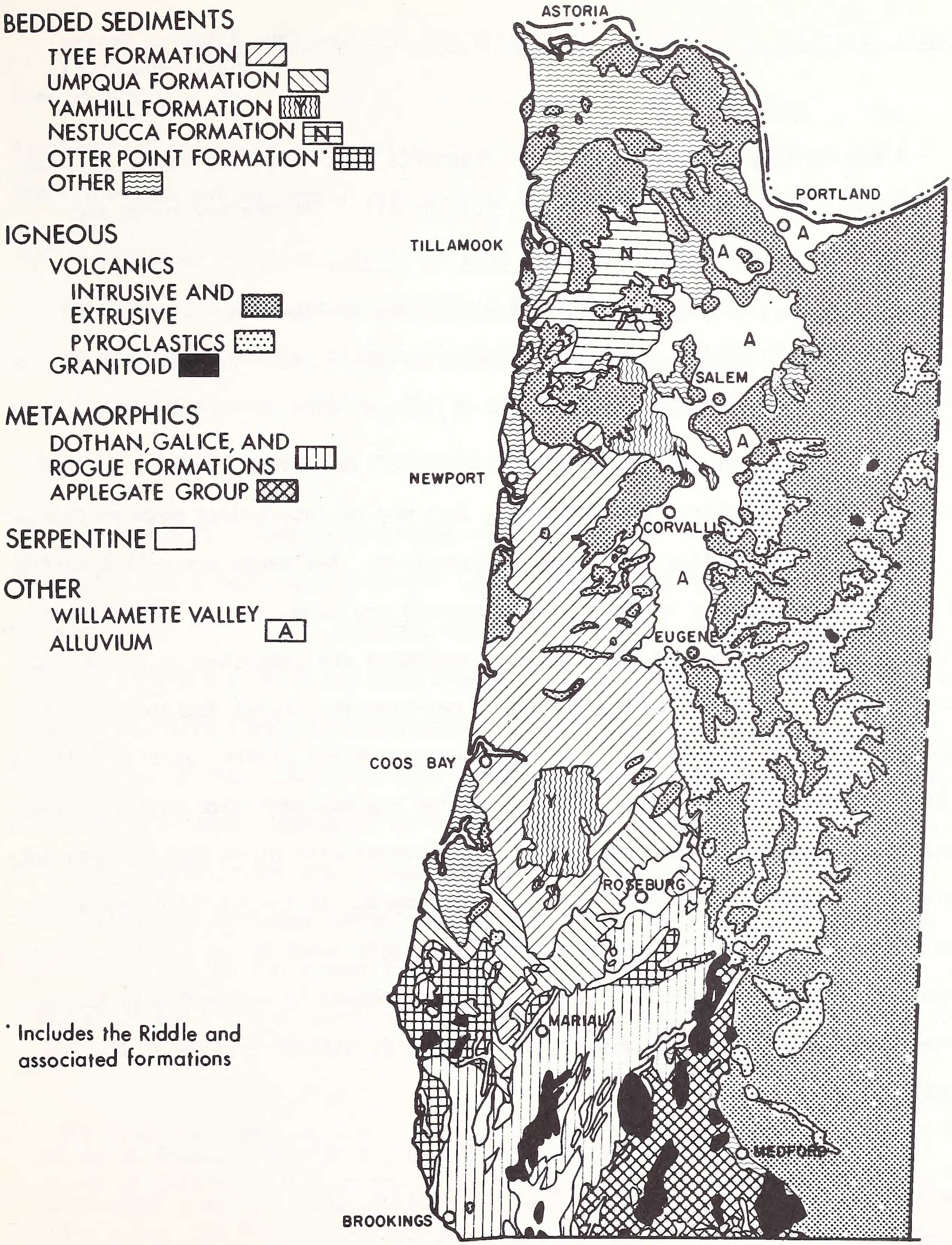


FIGURE 2 – GEOLOGIC MAP OF WESTERN OREGON

Characteristics of Common Geologic Materials (Adapted from Baldwin; Grout; Wells and Peck)

1. Bedded Sediments

A sedimentary rock is composed of fragments that have been deposited from a transporting medium, such as water, ice, or air. Sedimentary rocks are usually deposited in layers known as beds or strata, that are separated by bedding planes. Bedding is indicated by changes in particle size or color. The beds vary in thickness and are essential parallel although they may be warped or tilted from the horizontal by uplift, folding, and faulting.

The bedded sediments may include layers of fine-grained fragmental rocks such as shale, mudstone, and siltstone, that may be interbedded between thicker layers of medium-grained rocks such as sandstone. Sediments are called marine if they were deposited in the sea or estuaries and nonmarine, or continental, if they were deposited in fresh water. Sediments are compacted by the weight of overlying water and sediments and are cemented to varying degrees of hardness by minerals preciptated from ground water. Flood waters, glacial melt, or shore waves may deposit sand, gravel, cobbles and boulders into poorly sorted masses of material. When this material is covered with other deposits and saturated with waters rich in minerals, a conglomerate is formed. This material may be weakly to strongly cemented and the texture tends to vary both vertically and laterally. The cementing material may be removed by weathering processes when conglomerate deposits are exposed, either by natural erosion or by road construction.

A group of beds of sedimentary rock that are distinctive enough to be described and mapped as a unit is called a formation, and is given a formational name. Five formations of bedded sediments that occupy the greatest area in western Oregon are the Tyee, Yamhill, Umpqua, Otter Point, and Nestucca.

The Tyee occupies the greatest area of any formation in western Oregon (see Figure 2). The Tyee has massive beds, each of which grades upward from sandstone to siltstone. The colors range from medium-gray to bluish-gray on fresh surfaces and may appear tan to gray on weathered surfaces (see Figures 3a and 4).

The Yamhill formation contains massive gray to greenish-gray sandstone with thinner beds of medium-gray to dark-gray, mudstone, shale, or siltstone (see Figures 3b and 5). The Yamhill is found in two general areas (Figure 2); one west of Salem and another northeast of Coos Bay.

The Umpqua is a complex formation with three major units or subdivisions. The lowest (or oldest) unit contains some volcanic rock in addition to beds of sedimentary rock. This material may be seen along Highway 42 between Coquille and Myrtle Point and also around Roseburg. The middle unit grades upward from thick layers of conglomerate through sandstone to siltstone; this material may be seen between Tenmile Creek and Lookingglass Creek southwest of Roseburg. The upper (youngest) unit is composed of pebbly conglomerate (Figures 3c and 6) that grades upward into siltstone and is found from Camas Valley almost to Dutchman Butte, southwest of Roseburg. Some portions of the Umpqua formation may be darker than either the Tyee or Yamhill formations (Figures 3d and 7); the layers of siltstone, in particular, tend to be very dark.

The Nestucca formation covers a large block northwest of Salem and is composed of interbedded siltstone (Figures 3e and 8), claystone and sandstone. In many places the Nestucca formation is intersected by flows of volcanic rock.

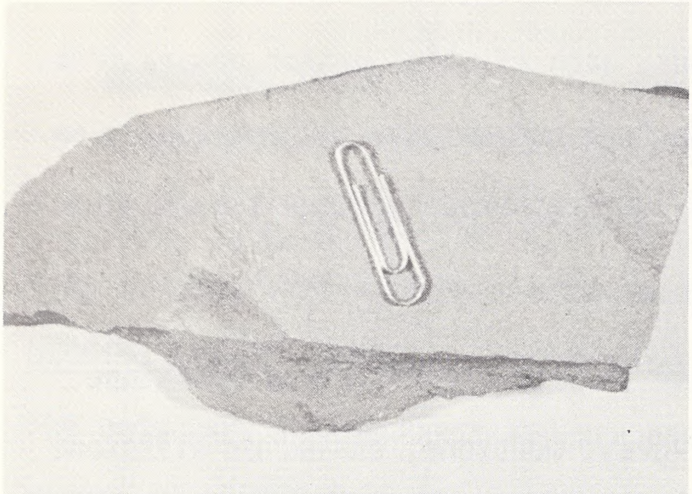


Figure 3a. Tyee sandstone.

Figure 3b. Yamhill formation.

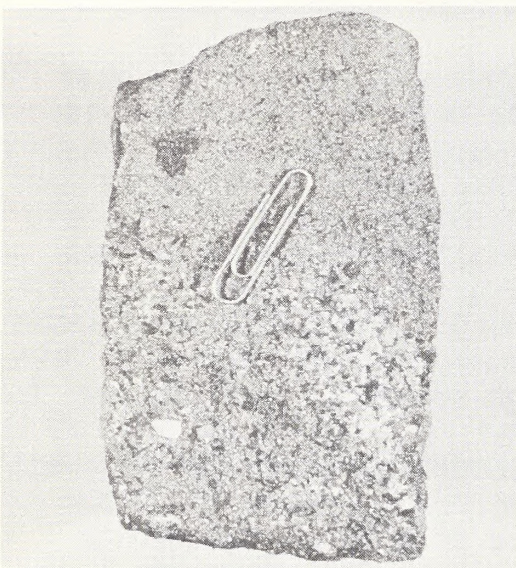


Figure 3c. Conglomerate from the Umpqua formation.

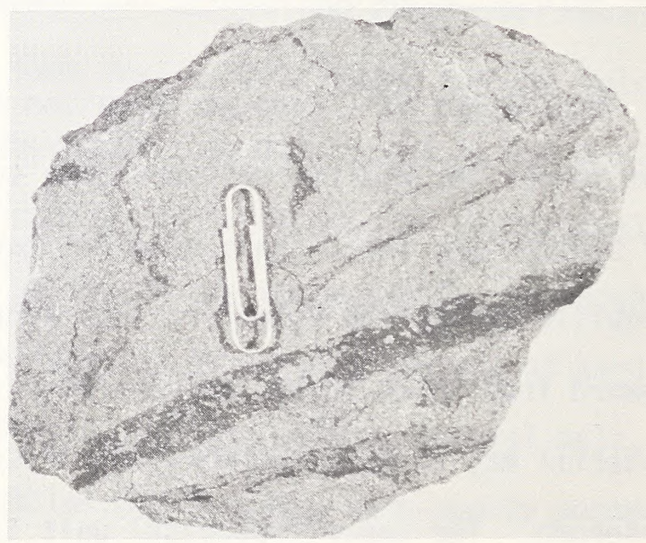


Figure 3d. Umpqua formation; note the fossilized vegetation.

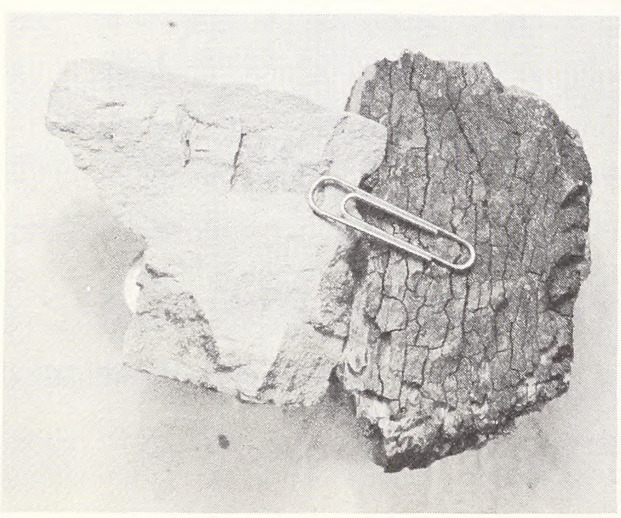


Figure 3e. Siltstone from the Nestucca formation.

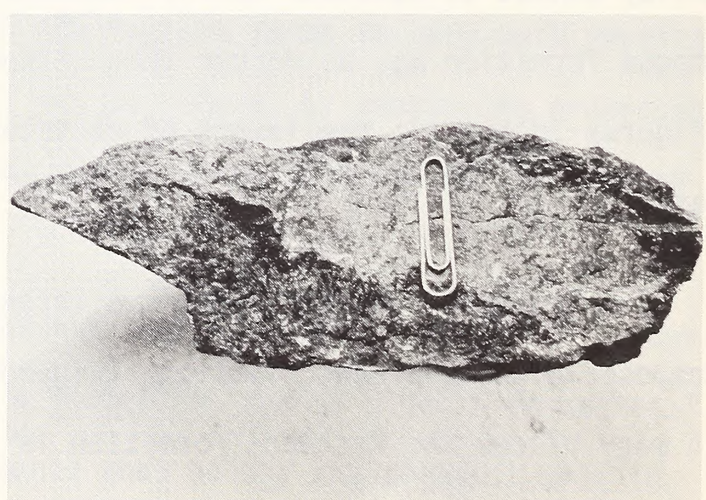


Figure 3f. Otter Point formation.

Figure 4. Tyee formation

Figure 5. Yamhill formation

Figure 6. Conglomerate portion of the Umpqua formation

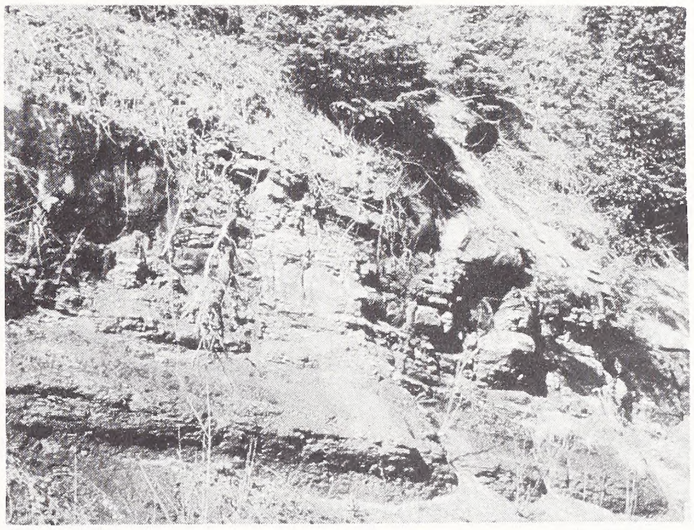


Figure 7. Sandstone portion of the Umpqua formation

Figure 8. Nestucca formation showing weathered siltstone

Figure 9. Otter Point formation

The appearance of the Otter Point formation, and associated formations with similar characteristics, is that of highly sheared, tan, dark-gray or black sandstone with interstratified thin mudstone, minor conglomerate, and volcanic material (Figures 3f and 9). This material occurs in small areas from Myrtle Creek (south of Roseburg) on west to a large block along the southwest Oregon coast.

The remainder of the bedded sediments is composed of scattered formations which have geologic characteristics and slope stability problems similar to the sedimentary formations already discussed.

2. Igneous Rocks (exclusive of granitoid rock)

Igneous rocks may be divided into those that have cooled from molten masses beneath the surface of the earth, called intrusive rocks, and those that have flowed or been forcibly extruded upon the surface to cool, called extrusive rocks.

Intrusive igneous rocks are found in large, deep-seated irregular masses called batholiths, in smaller masses known as stocks, in tabular bodies known as sills, that lie parallel to enclosing bedded sedimentary rocks, and in tabular masses known as dikes that cut across the enclosing strata. Some of the smaller masses, such as dikes and sills, cool rapidly into fine-grained rock. Many of the prominent peaks and ridges in the Coast Range are the result of intrusions of igneous material into sedimentary rock where erosion has removed the softer sedimentary material to expose the harder igneous rock.

The western portion of the Cascade Range is underlain by thick layers of relatively hard extrusive igneous rocks, such as basalt and andesite that are exposed extensively in the northern portion and along the higher elevations to the south. Some extrusive flows take place beneath water where the lava cools into rounded masses commonly 2 to 3 feet across. These rocks are referred to as

marine basalt or pillow lavas because of their characteristic shape (Figure 10) and these tend to be relatively soft and easily eroded. This material is common in a large block of igneous rock in the Coast Range northeast of Tillamook (Figure 2).

Photographs of four common extrusive and intrusive rocks are shown on Figure 11.

3. Pyroclastic Rock

Pyroclastic rock is a type of extrusive igneous rock that was expelled from volcanic vents. This material is partially molten when it is expelled and the individual pieces may fuse together to form a weak, porous rock. More commonly, the angular fragments are deposited with volcanic ash to form volcanic breccia (pronounced "breshia") that appears as coarse, angular fragments 1/4 inch to 2 inches in size within a matrix of fine volcanic ash (Figure 12). If the size of the fragments imbedded in the ash are about 1/4 inch or smaller, then the resulting pyroclastic rock is known as tuff (pronounced "tough"); a photograph of this material is shown in Figure 13.

The strength and hardness of pyroclastic rocks depend to a large extent upon the amount of fusion and compaction that takes place between particles at

Figure 10. Pillow lava showing characteristic rounded shapes

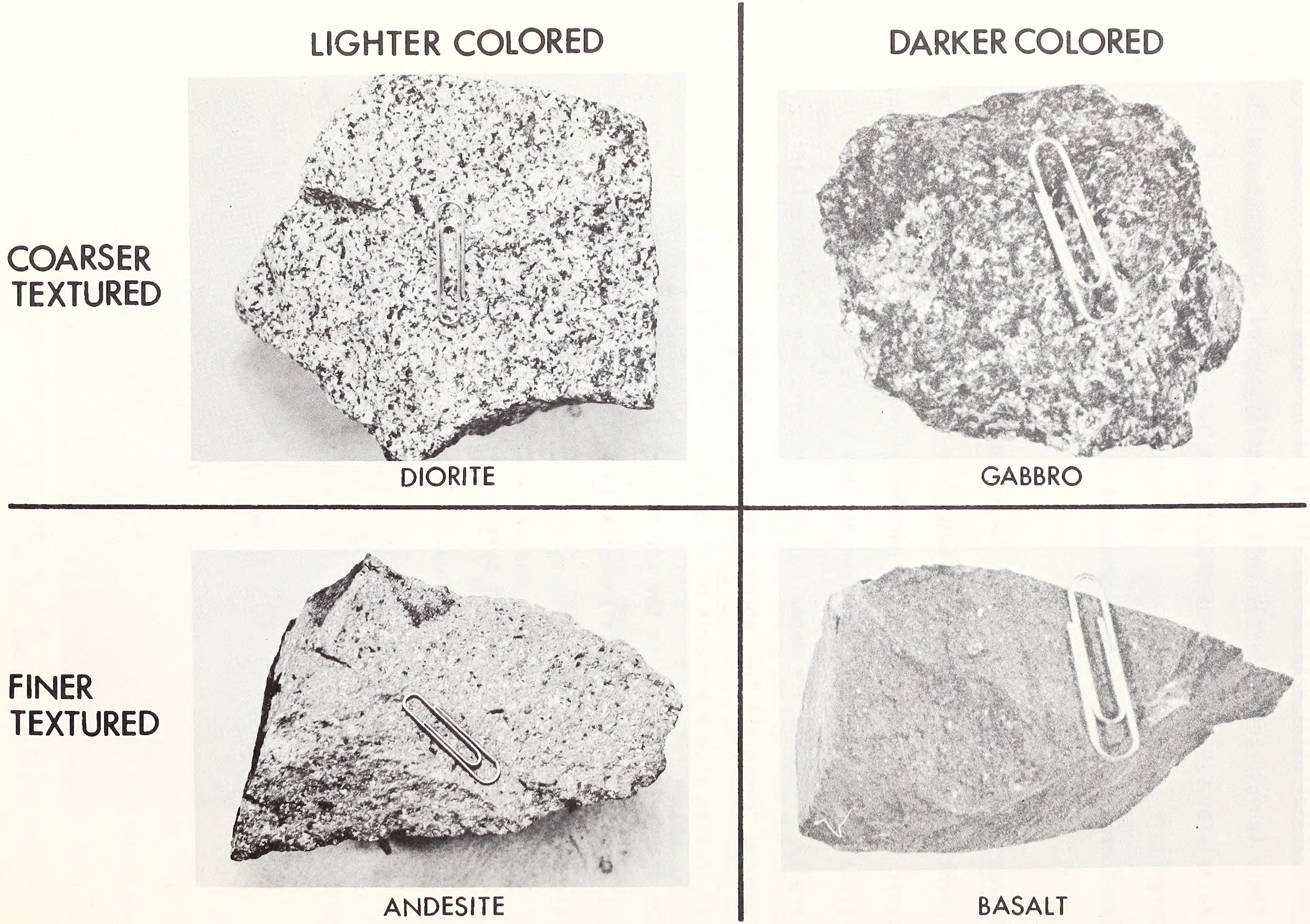


Figure 11. Four common intrusive and extrusive igneous rocks

the time of deposition. Generally, pyroclastic rocks are relatively soft and the volcanic ash matrix weathers rapidly to clay. Various kinds of tuffs and breccias are found over large areas of the western slopes of the Cascades, and as inclusions within bodies of extrusive igneous rock in the Coast Range.

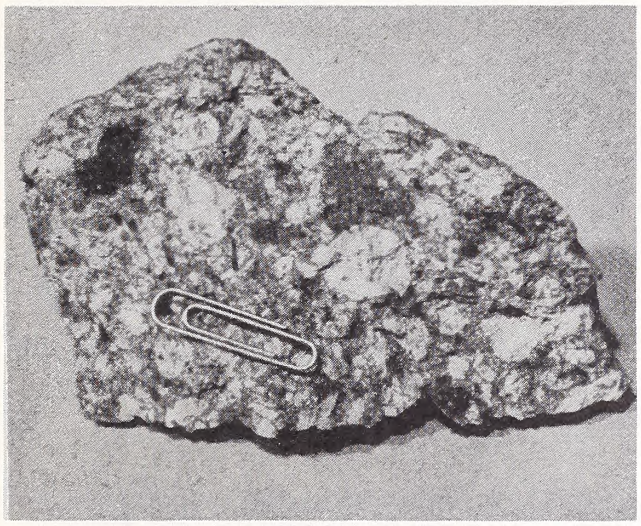


Figure 12. Volcanic breccia with coarse, angular fragments 1/4" to 2" in size

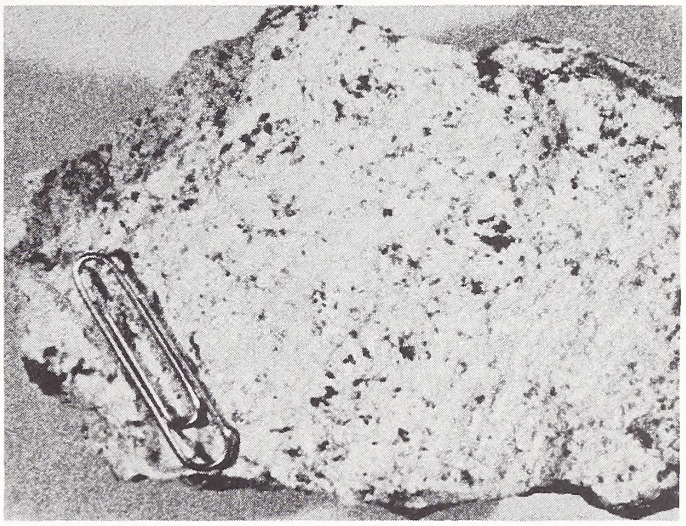


Figure 13. Volcanic tuff with fragments 1/4" or smaller imbedded in ash.

4. Granitoid Rocks

Granite is a light-colored, coarse-grained rock (Figure 14) which is formed when molten material is intruded into surrounding rock; the rate of cooling is very slow and mineral crystals grow large. Variations in the chemical composition of this intrusive material creates a wide spectrum of granitoid (or granite-like) rocks (Figure 15). Weathered granitoid rock tends to crumble easily into a coarse "sand" as the weathering process degrades the grain-to-grain contact that holds the large crystals together. Granitoid rocks are found in the Klamath Mountains (also known as the Siskiyou Mountains) and in isolated spots in the Cascades (Figure 2).

5. Metamorphic Rocks

Metamorphic rocks are formed from any existing rock by changes caused by heat, pressure, and/or chemical alteration. Either the pressure of extremely thick layers of sedimentary rock or the heat from large bodies of intrusive

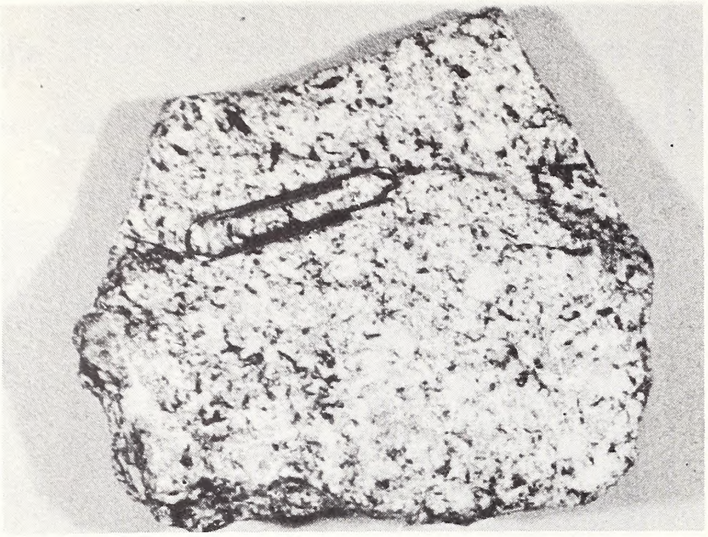


Figure 14. Granite is light colored and coarse-grained

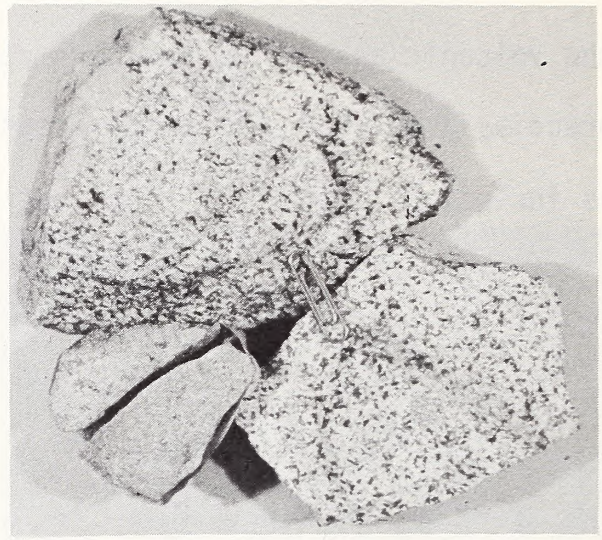


Figure 15. Granitoid rock resembles granite and has similar characteristics for road building

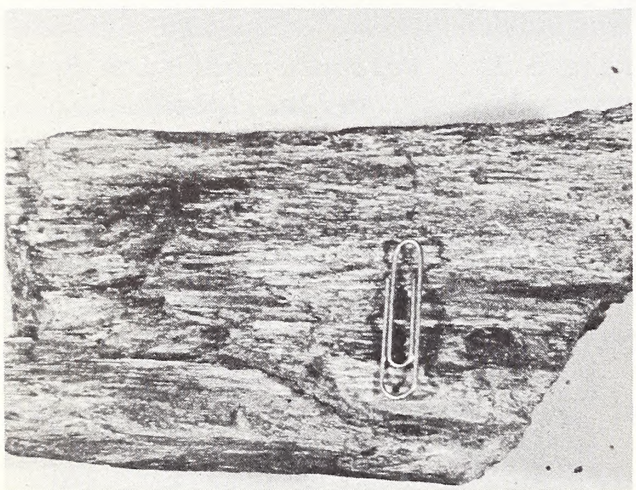


Figure 16. Colebrook schist with a pronounced platy appearance

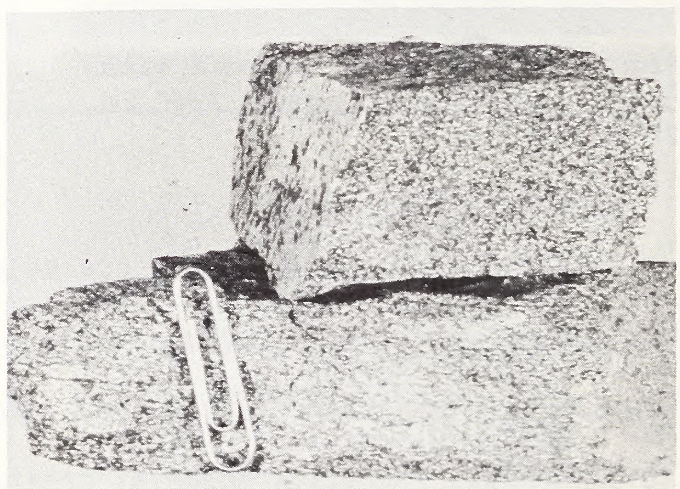


Figure 17. Schist from Evans Creek weathers easily into a "sand"

Figure 18. Gneiss has relatively thick bands of colored material

igneous rocks can alter the texture of the rock with an accompanying rearrangement of elements into different minerals. Ground water can also carry chemicals into or away from the area where metamorphism is taking place. Limestone may be metamorphosed into marble, sandstone into quartzite, and mudstone into slate. Further metamorphism of slate with perhaps the intrusion of igneous fluids may result in schist (Figures 16 and 17), a fine-grained crystalline rock with a platy appearance. Metamorphism of other materials, commonly granitoid rocks, may produce gneiss (pronounced "nice"), which is a relatively coarse-grained rock with layers of light and dark minerals (Figure 18).

The only reason we see the results of metamorphism is that geologic uplift and erosion exposes the cores of mountains that contain metamorphic rock. When the metamorphic rocks are exposed to the atmostphere they are in a different environment than when formed, and many of the minerals are unstable and break down. The Klamath Mountains have extensive areas of metamorphic rocks of various types.

The metamorphic rocks of western Oregon can be roughly subdivided into two groups - those from the Galice, Dothan, and Rogue formations (the Galice group), and those of the Applegate group. Those isolated portions of metamorphic rock that are located west of the Dothan formation consist of schist and light- and dark-banded gneiss from the Galice and Rogue formations. The remainder of the Galice group consists of partly metamorphosed sedimentary rocks and metamorphosed volcanic rocks. The Applegate group is composed of metamorphosed sedimentary rock, including dark, pebbly conglomerate and some marble and quartzite, and metamorphosed volcanic rocks including green to greenish-gray breccias, tuffs, and intrusion of basaltic or andesitic rocks. There is a large area of

schist with thin plates of black and white minerals (Figure 17) that is found along the East Fork of Evans Creek (a tributary of the Rogue River) and north to the town of Tiller on the South Umpqua River.

6. <u>Serpentine</u>

Serpentine is a rock that exhibits characteristics of both metamorphic and intrusive igneous rocks. It is metamorphosed <u>peridotite</u> that may have been squeezed into fault zones in the surrounding rock in the manner of igneous rocks. However, while intrusive rocks are molten during intrusion, serpentine is intruded as a relatively cold mass that causes shearing and gives serpentine its characteristic "slick-sided" appearance. The term <u>serpentine</u> refers to the mineral and the term <u>serpentinite</u> refers to the rock mass that contains the mineral. "Serpentine" will be used for both terms for the purpose of simplicity.

The color of serpentine ranges from yellow-green, bluish-green, or olive-green to almost black (Figures 19 and 20). Note in Figure 2 that serpentine appears as extensive areas and also quite frequently as thin belts or streaks, oriented southwest to northeast in the Klamath Mountains and along the southwest coast.

Figure 19. Serpentine may range from yellow-green, through bluish-white, to black

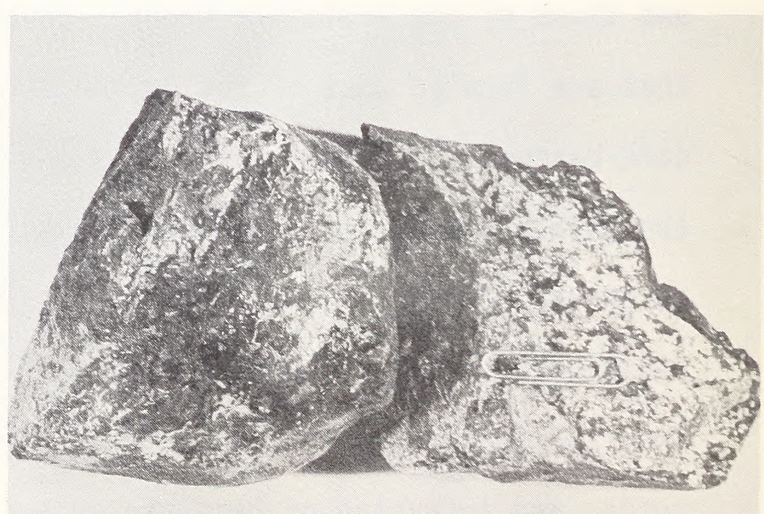


Figure 20. Serpentine has a silky sheen and fractures into sharp pieces

Geologic Features That Affect Slope Stability

There are certain geologic features that have a profound effect upon slope stability and consequently upon the results of road construction in an area. Many of these geologic features can be observed in the field and also identified on topographic maps and aerial photographs. In some cases these geologic features may be deduced by comparing geologic and topographic maps. This section will attempt to illustrate those geologic features that have a significant effect upon slope stability and the techniques that may be used to identify them.

1. Faults

The geologic uplift that accompanies mountain building is quite evident in western Oregon, particularly in the Coast Range and Klamath Mountains. Stresses built up in layers of rock by the warping that accompanies uplift is usually relieved by fracturing. These fractures may extend for great distances both laterally and vertically and are known as faults. Often the material on one side of the fault is displaced vertically relative to the other side and sometimes igneous material is intruded into faults. The simplified geologic map of Figure 2 is too small to show faults but the orientation of the major veins of serpentine indicate a pronounced southwest to northeast trend for major fault zones in the Klamath Mountains. Larger scale geologic maps also show this trend for major and minor faults over much of the Coast Range. Faults are the focal point for stress relief and for intrusions of igneous rock and serpentine; therefore, fault zones usually contain rock that is fractured, crushed, or partly metamorphosed. It is extremely important to recognize that fault zones are zones of geologic weakness and, as such, are critical in road location. Faults often leave topographic clues to their location.

An example of matching a geologic map to a topographic map is shown in Figure 21. An enlarged township (R. 8 W., T. 13 S.) from a geologic map (Wells and Peck) is shown in the upper corner of a portion of the USGS Alsea Quadrangle topographic map (15 minute series). The faults, shown as heavy black lines on the geologic map, are outlined with heavy black lines on the topographic map. The location of these fault zones is established by looking for:

A. Saddles, or low sections in ridges, which are aligned in one general direction from one drainage to another.

B. Streams that appear to deviate from the general direction of nearby streams.

Note that the proposed locations of the fault zones on the topographic map follow saddles and drainages in reasonably straight lines.

A rectangular area is outlined on the topographic map in Section 21, and a stereogram that was developed from aerial photography of this area is shown in Figure 22. The locations of the fault zones were transferred from the topographic map to the stereogram. An examination of the stereogram through a stereoscope will show that there is a large slope failure on the fault zone. This is an old failure as indicated by the lack of exposed soil and by the fact that mature timber was harvested from this area. An examination of this area on the ground showed that igneous rock had intruded into the fault, that the slopes at A and B are actively moving, and that the slope at C has slid into the stream since these photographs were taken.

Aerial photographs should be carefully examined for possible fault zones when neither geologic maps nor topographic maps offer any clues. Figure 23 is a stereogram of a portion of Cow Creek, south-southwest of Roseburg, together with a portion of the topographic map of this area. A possible fault zone is indicated

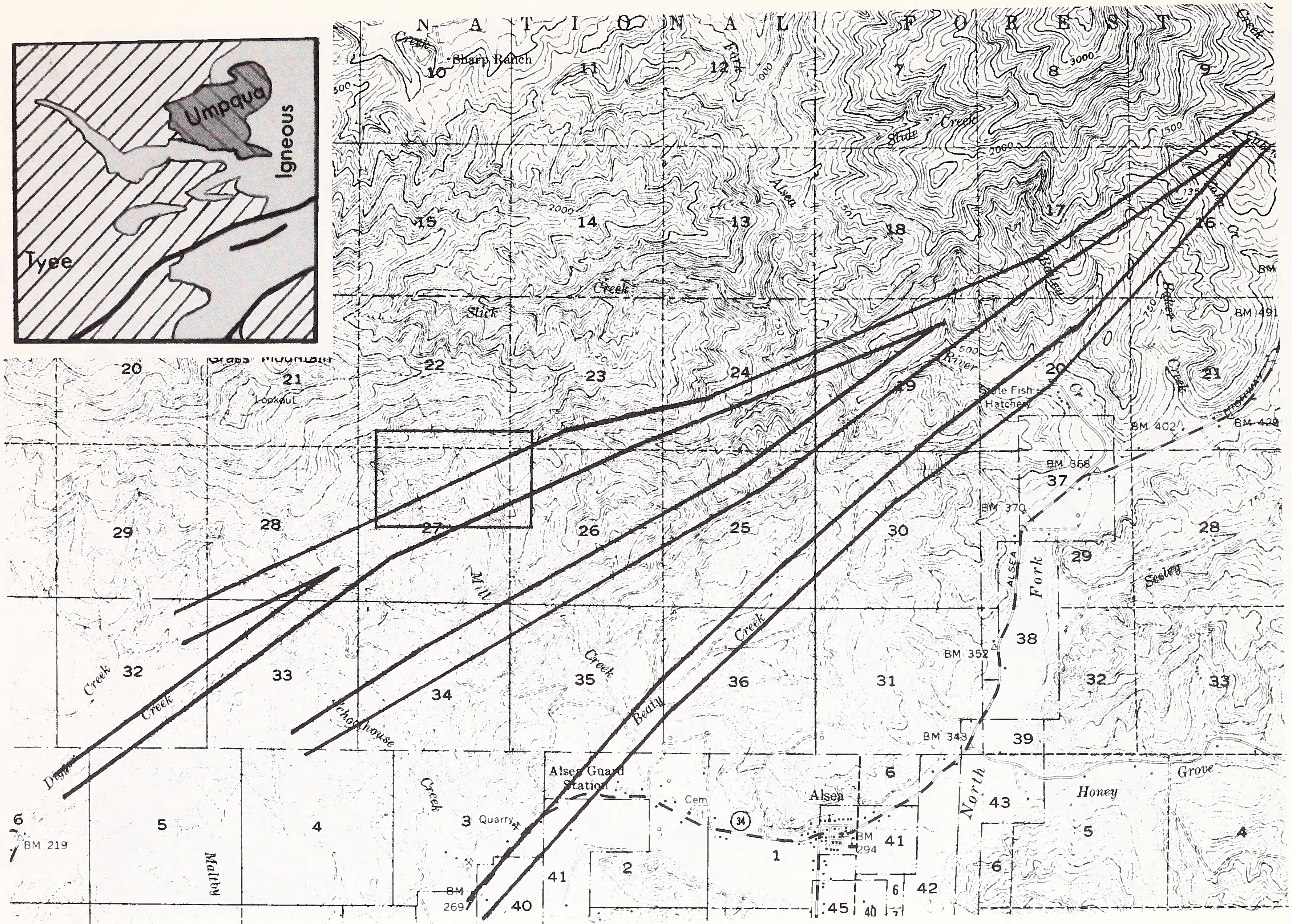


Figure 21. Suspected fault zones are indicated by the alignment of saddles in ridges and by the direction of stream channels. Geologic map of R. 8 W., T. 13 S., is found in upper left corner. Major faults are shown as heavy dark lines on geologic map.

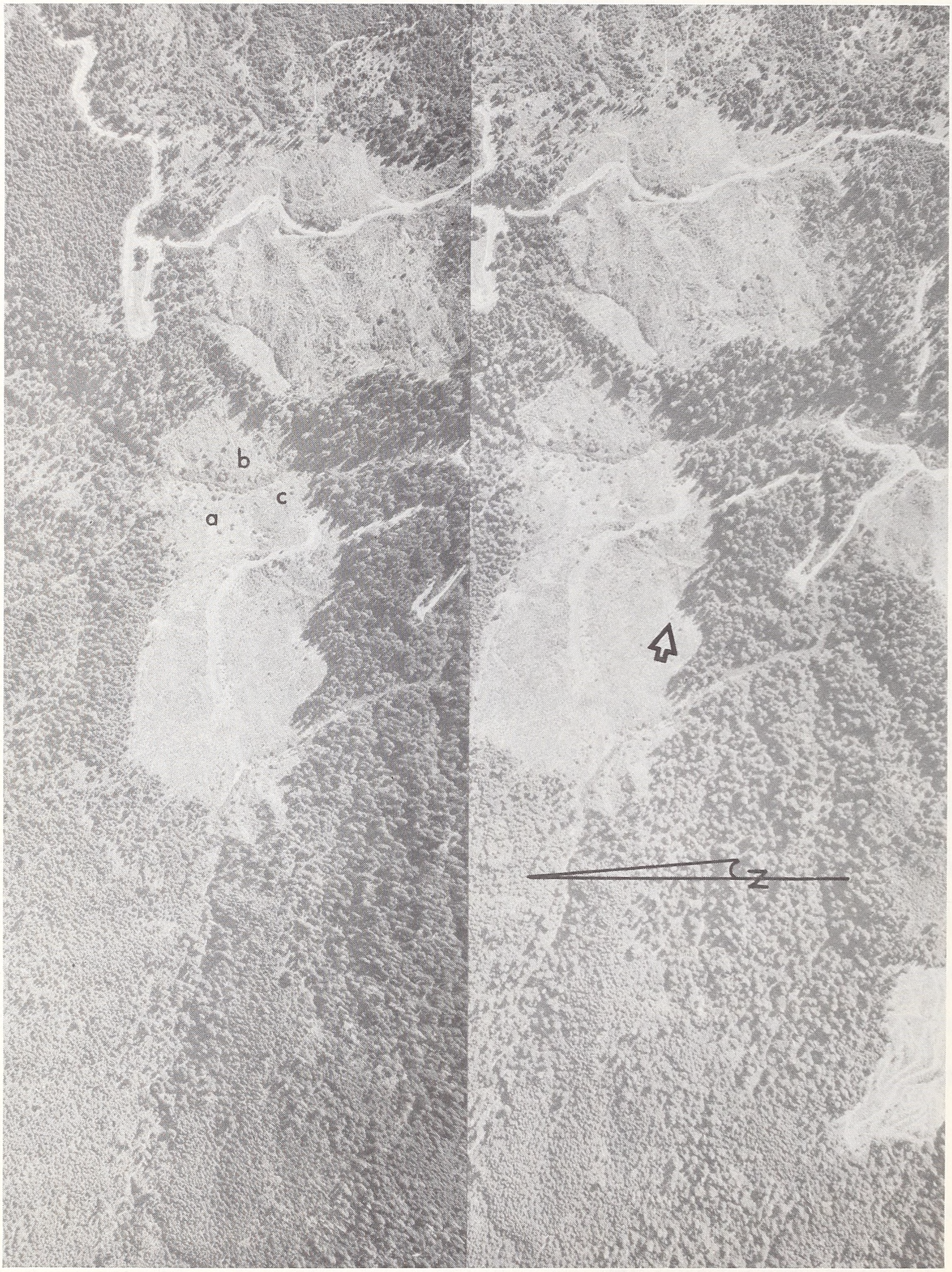


Figure 22. Stereogram of fault zone outlined in Section 27 of Figure 21. Large slump in center of photo; actively failing slopes at a and b. Arrow points to a dry sag pond below the slump.

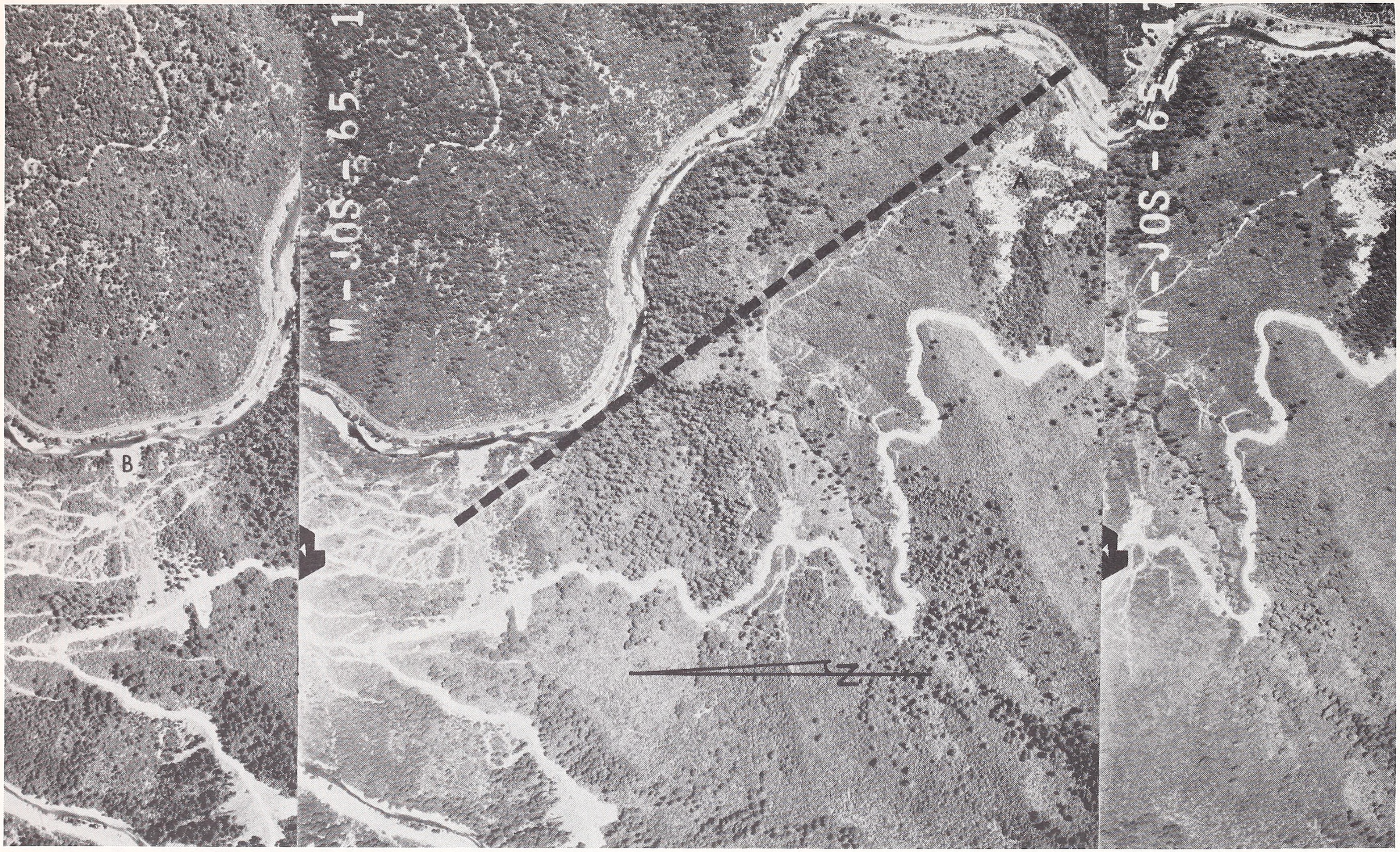


Figure 23. Stereogram of a possible fault zone. The location of the fault is indicated by the dashed line through the low saddle between the large, older slump at A and the newer slope failure at B.

on the stereogram; note that it passes through several saddles and begins and ends in Cow Creek. Also note the large, old slide at A and the newer slide at B. These photographs were taken in 1965; since then a highway has been constructed along Cow Creek on the bank across from the railroad. The slide at B has enlarged, has been actively moving, and has buckled the highway at the base of the slide. Further evidence of a fault zone through this area is shown in the photograph of a rock from the slide at B (Figure 24). The important feature is the slick, shiny surfaces, called "slickensides", that are caused by the intense heat developed by friction on sliding surfaces within a fault zone.

Figure 24. A rock from the rockslide at point A on Figure 3. Note the shiny surface.

Field personnel should be alert for on-the-ground evidence of faulting when neither geologic maps nor topographic maps provide definite clues to the location of faults. For example, Figure 25 contains portions of the Sitkum and the Ivers Peak quadrangle topographic maps. Note that these maps do not show any definite indication of a fault zone. Figure 26 is a stereogram of a suspected fault zone; this stereo coverage is outlined in black on Figure 25. Timber has been harvested from several of the small drainages and fractured and uptilted rock may be seen at Point A. Figure 27 shows a photo of Point A taken from the spur road at B. This direct evidence of faulting probably could not have been

Figure 25. A portion of the Ivers Peak and Sitkum Quadrangle topographic map (T. 26 and 27 S., R. 9 and 10 W.). There is no indication of a fault zone on these maps. The outlined area identifies the stereo coverage on Figure 26.

Figure 26. A stereogram of the area outlined on Figure 25. Fractured and up-tilted rocks are shown at point A. A ground photo of this feature photographed from point B is shown in Figure 27. Changes in the slope of the ground at points C and D indicate a possible fault zone through these points.

seen on aerial photos before timber harvest, but field personnel may observe the exposed rock and a more intensive reconnaissance may be started. In this case, the faulting at A together with the topographic clues at C and D indicate a fault zone that extends through C and D.

Figure 27. Photograph of the fault zone shown at point A on Figure 26

The purpose of this discussion about faults is to emphasize that geologic maps, topographic maps, information from aerial photos, and on-the-ground clues should all be used to help locate fault zones because faults increase the probability of slope failure.

2. <u>Strength of the Rock and Resistance to Erosion</u>

A second set of geologic features are concerned with the rock material itself: the competence, or inherent strength of the rock, and the ability of the rock to resist weathering. The term competence, as defined by engineering geologists, refers to the ability of the rock material to resist compression, tension, etc., without crumbling or fracturing. Competence depends upon the material itself, how badly it is fractured, and the thickness of the beds or layers. Thin-bedded material, or thick-bedded rock that is badly fractured, may be relatively incompetent. The ability of a rock to withstand the weathering process is also an important factor in road construction. For example,

massive granite can be considered to be more competent than sandstone, but the ease with which granite can disintegrate once it has been exposed during construction usually creates more road maintenance problems than does sandstone.

Geologic maps and topographic maps used together can help locate, relatively accurately, the boundary between geologic materials with different values of competence and resistance to weathering. Figure 28 is a portion of a topographic map of the Camas Valley quadrangle west-southwest of Roseburg. Note the change in slope gradient from the Tyee sandstone to the underlying Umpqua formation. The boundary of these two formations is indicated by the hatched line. The Tyee formation is more competent and has a greater resistance to weathering than does the Umpqua formation. This difference is indicated by the cliff-forming character of the Tyee formation. The Umpqua formation weathers rapidly to moderate slopes because of the high percentage of siltstone in the formation in this area. A picture of the contact between the Tyee and the darker Umpqua formation is inserted in the upper corner of Figure 28. The location of this photo is indicated by the X in the upper left corner of the map.

3. Slope of Bedding Planes

There are many locations where sedimentary rock has been warped or tilted and the bedding planes may be steeply sloped. If a road is planned for such an area, it is important to determine the slope of the bedding planes relative to the ground slope. In areas where bedding planes are approximately parallel to the slope of the sidehill, road excavation may remove enough support to allow large chunks of rock to slide into the road. If preliminary surveys reveal that these conditions exist, then the route may need to be changed to the opposite side of the drainage or ridge where the bedding planes slope into the hillside.

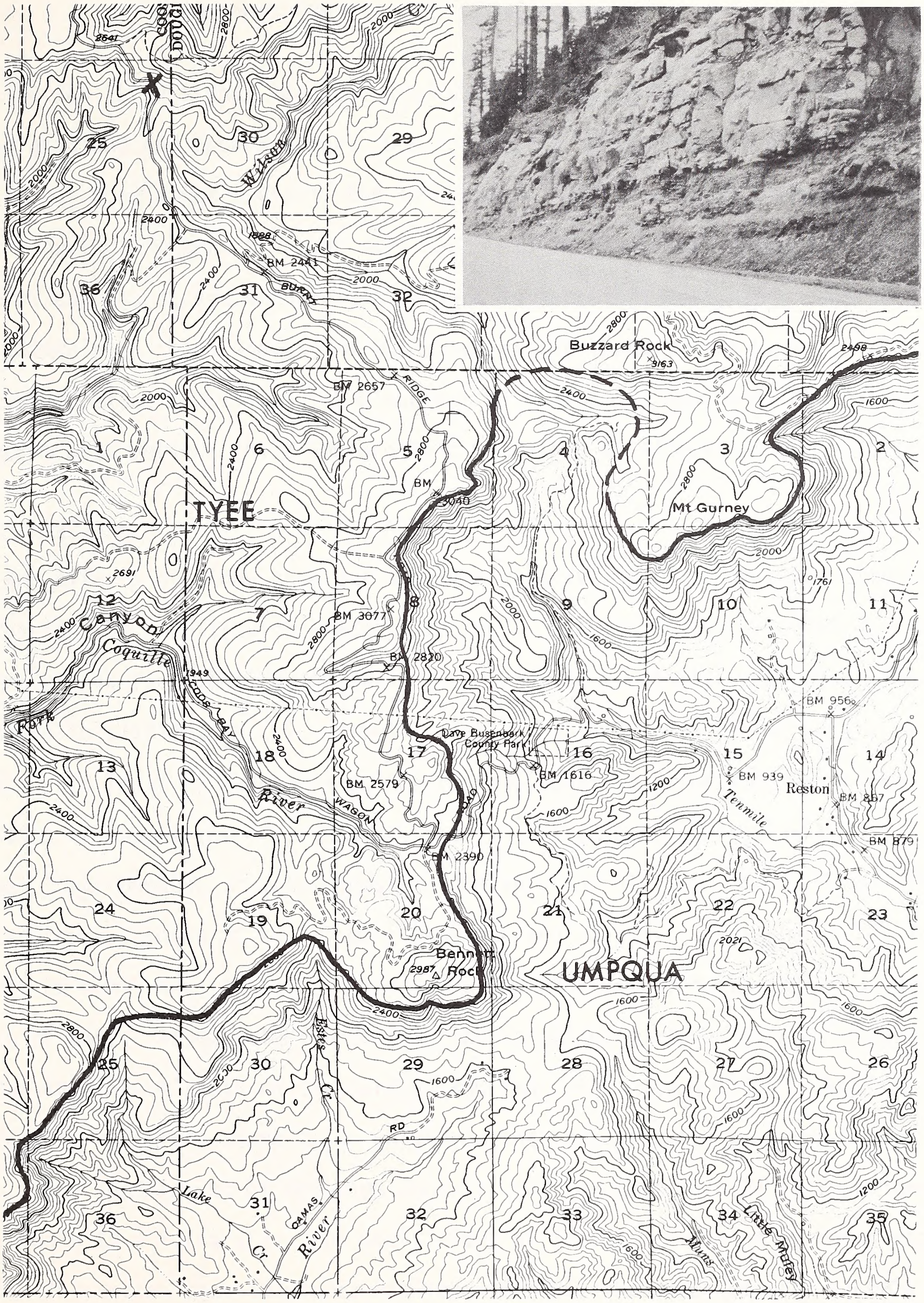


Figure 28. Topographic map of the Camas Valley Quadrangle. The Tyee sandstone is a more competent formation than the Umpqua formation in this area, and forms cliffs at the junction of these two formations. A photo of the contact between these two formations is shown in the upper right. The location of this photo is shown by the X in the upper left.

SOIL MECHANICS AND SLOPE STABILITY

The two factors that have the greatest effect upon slope stability are slope gradient and ground water. Generally, the greater the slope gradient and the more ground water present, the less stable will be a given slope regardless of the geologic material or the soil type. It is absolutely essential that foresters, engineers, and technicians engaged in locating, designing, constructing and maintaining roads understand why slope gradient and ground water are so important to slope stability. This section will describe how slope and ground water interact with various soils and geologic materials to affect slope stability.

Slope Gradient

The effects of slope gradient on slope stability can best be understood by discussing the stability of a pure, dry sand. Slopes in this material depend entirely upon frictional resistance to sliding for stability. Frictional resistance to sliding, in turn, depends upon (1) that portion of the weight of an object that rests on the surface, and (2) the coefficient of friction. The fraction of the weight of an object that is exerted on a surface is known as the normal force because it acts normal to, or perpendicular to, the surface. The normal force changes as the slope of the surface changes. The upper curve in Figure 29 shows how the slope gradient changes the normal force (N) of a 100# block of sand. As expected, when the slope gradient is zero the entire weight of the 100# block rests on the surface and the normal force = 100#. When the surface is vertical, there is no weight on the surface and the normal force is zero. The coefficient of friction converts the normal force (N) to frictional resistance to sliding (F). The coefficient of friction for sand averages about 0.70. This means that the force required to slide the block of sand along a surface is equal to 0.7 times the normal force. The lower curve in Figure 29

shows how the frictional resistance to sliding changes with slope gradient. The lower curve was developed by multiplying the values of points on the upper curve by 0.7. Therefore, when the slope gradient is zero, the normal force = 100# and 70# of force is required to slide the block along the surface. When the slope gradient is 100 percent, the normal force = 71# (from point 3 on the upper curve, and 50# (or 71# X .7) is required to slide the block along the surface (from point 3 on the lower curve).

That portion of the weight which acts downslope, or parallel to the surface, provides some of the force to overcome frictional resistance to sliding. The downslope force, also known as the driving force, depends upon the slope gradient and increases as the gradient increases, as shown in Figure 30. Obviously, when the slope gradient becomes steep enough the driving force will exceed the frictional resistance to sliding and the block will begin to move. Figure 31 shows the curve for frictional resistance to sliding (from Figure 29), superimposed on the curve of the driving force (from Figure 30). These two curves intersect at 70 percent slope gradient. This means that for slope gradients less than 70 percent the frictional resistance to sliding is greater than the downslope component of the weight of the block and the block will remain in place on the surface. For slope gradients greater than 70 percent, the block will slide because the driving force is greater than the frictional resistance to sliding.

This discussion has been confined to the case of a pure, dry sand, a case which is seldom found in soils, but the principles of the effects of slope gradient and frictional resistance to sliding apply to any dry soil. Soils contain varying amounts of fine particles (silt and clay) that affect the strength of the soil. A block of uniform soil fails, or slides, by shearing. That is, one portion of the block moves past another portion of the block in a parallel

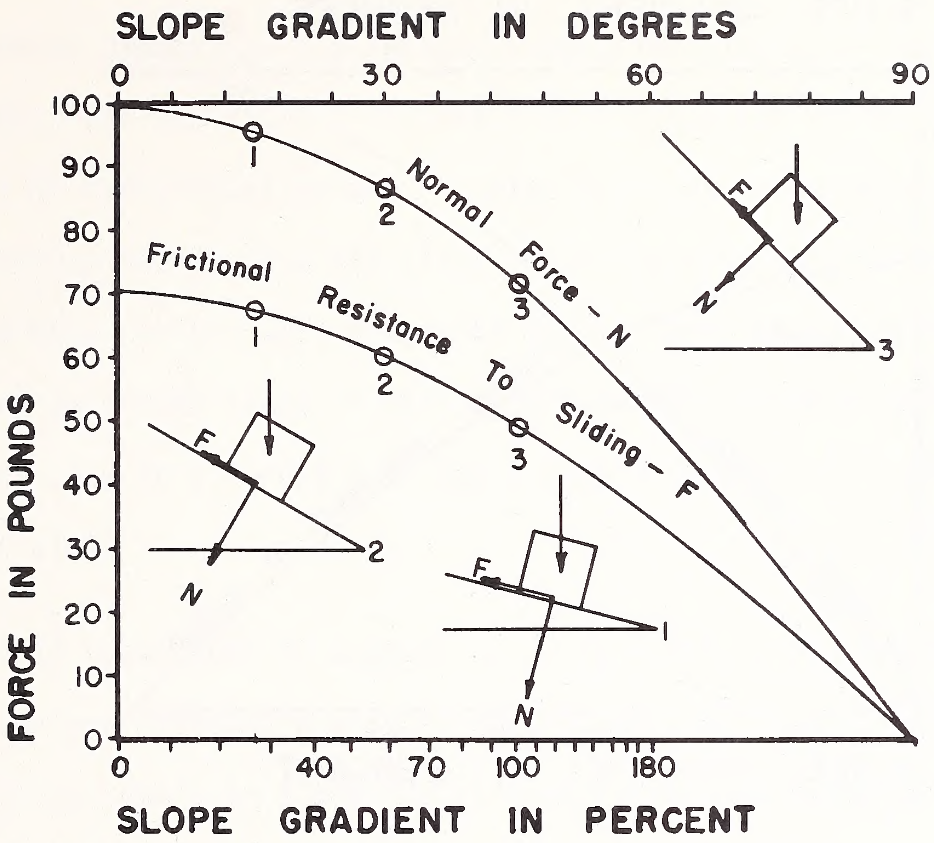


Figure 29. The upper curve shows that the portion of the weight of an object acting on a surface changes as the slope of the surface changes. The lower curve shows how the frictional resistance to sliding changes with the slope of the surface.

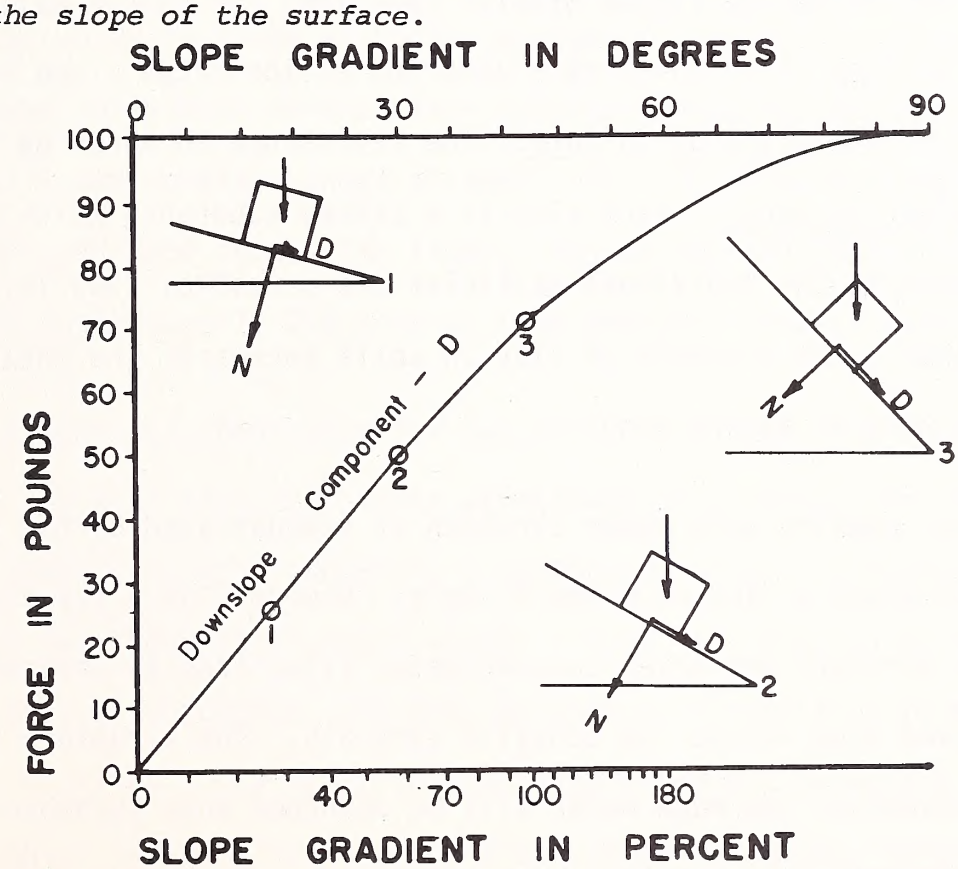


Figure 30. This curve shows the downslope component of the weight of and object increases as the slope of the surface increases.

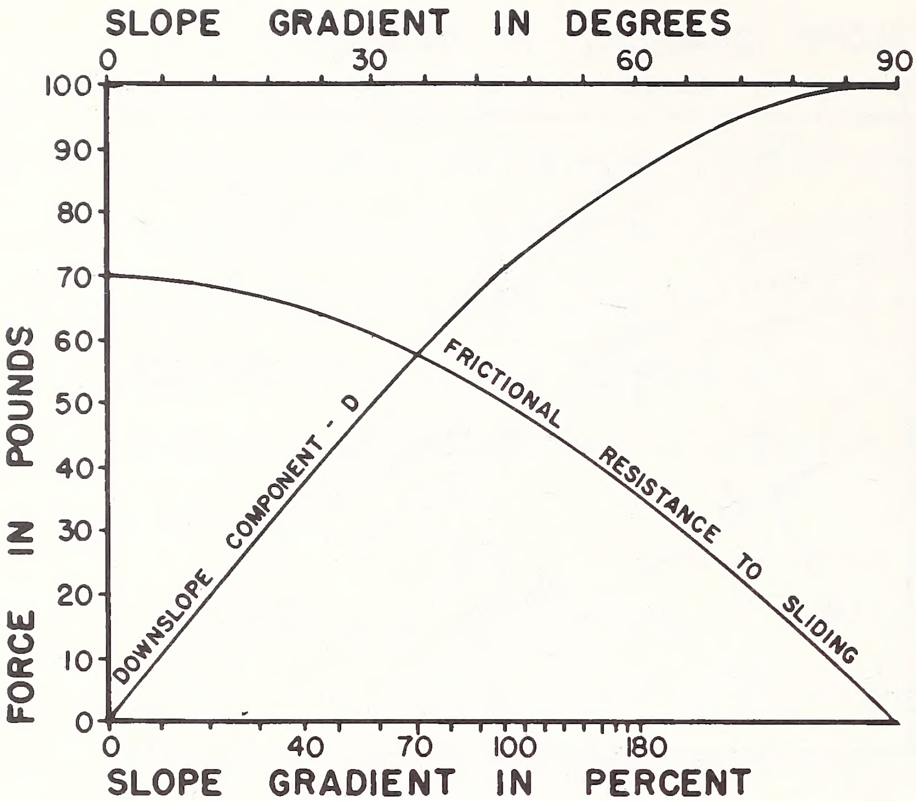


Figure 31. This figure shows how the frictional resistance to sliding compares with the downslope component of weight and how these two forces determine the stability of an object. At slopes less than 70%, the object will not slide, at slopes greater than 70%, the object will slide.

direction. The surface along which this shearing action takes place is called the <u>shear plane</u>, or the <u>plane of failure</u>. The resistance to shearing is often referred to as <u>shear strength</u>. Pure clay is a sticky substance which develops shear strength because the individual particles are cohesive, that is, they stick to each other. The presence of clay in soils increases the shear strength of the soil over that of a pure sand.

A dry clay has considerable shear strength as demonstrated by the great force required to crush a clod with the fingers. However, as a dry clay absorbs water, its shear strength decreases because water films tend to separate the clay particles, and thus reduce its cohesive strength. The structure of the clay particle determines how much water will be absorbed and, consequently, how much the shear strength will decrease upon saturation. There are some clays, such as illite and kaolinite, that provide relative stability to soils, even

when saturated. However, a saturated montmorillonite clay causes a significant decrease in slope stability. Saturated illite and kaolinite clays have about 44 percent of their total volume occupied by water compared to about 97 percent for a saturated montmorillonite clay. This explains why montmorillonite clay has such a high shrink-swell potential (i.e., large change in volume from wet to dry) and saturated clays of this type have a very low shear strength. Thus, the type of clay in a forest soil has a significant effect upon slope stability (Paeth, et al.).

Granitoid rocks tend to weather to sandy soils as the weathering process destroys the grain-to-grain contact that holds the mineral crystals together. If these soils remain in place sufficiently long, they will eventually develop a significant amount of clay. If erosion removes the weathered material at a rapid rate, the resulting soil will be coarse-textured and will behave as a sand for purposes of slope stability analysis. It can be observed in many locations that soils that develop from granitoid material with a significant clay content will have greater shear strength and will support steeper cut faces than soils from granitoid rocks with little clay in the soil material. Granitic soils need approximately 20% clay to have adequate shear strength properties.

This discussion shows that for two soils developed from the same geologic material, the soil with the higher percentage of a stable clay will have the greatest shear strength. However, significant amounts of montmorillonite clay can reduce the shear strength of a soil. Also, for dry soils with the same particle size distribution, the ones on steeper slopes will have a greater potential to slide. The relative stability among soils depends on a comparison of their shear strength and the downslope component of the weight of the soil.

Ground Water

A common observation is that a hillslope or the sideslopes of a drainageway may be perfectly stable during the summer but may slide after the winter rains begin. The reason for this seasonal change in stability is due mainly to the change in the amount of water in the pores of the soil. The effect of ground water on slope stability can best be understood by again considering the block of pure sand. Frictional resistance to sliding in dry sand is developed as the product of the coefficient of friction and the normal force acting on the surface. A close-up view of this situation would show that the individual sand grains are interlocked, or jammed together by the weight of the sand. The greater the force that causes this interlocking of sand grains, the greater will be the ability to resist the shear force that is caused by the downslope component of the soil weight. As ground water rises in the sand, the water reduces the interlocking force because of the bouyant force exerted on each sand grain as it becomes submerged. This bouyant force is easily demonstrated by first weighing an object with a spring scale, then submerging the object in water and noting the decrease in the weight of the object. The difference in weight is caused by the uplifting force of the water.

The uplift force of the ground water reduces the interlocking force on the soil particles and this, in turn, reduces the frictional resistance to sliding. The <u>interlocking force</u> is the same thing as the <u>normal force</u> that was discussed at the first part of this section. These two terms will be used interchangeably. The uplift force of ground water is equal to 62.4 pounds per foot of water in the soil. If 100 pounds of sand that contains three inches (or 1/4 foot) of ground water rests on a horizontal surface, the normal force is 100 - 62.4 (1/4) = 100 - 15.6 or 84.4 pounds. The frictional resistance to sliding with this ground

water condition is 84.4 X .7 or 59.1 pounds. For 100 pounds of dry sand on a horizontal surface the normal force is 100 X .7 or 70 pounds. This example shows how ground water can reduce the frictional resistance to sliding.

The following examples emphasize how the presence of ground water can decrease slope stability. First, a layer of dry sand five feet thick was assumed and the weight of this material was 100 pounds per foot of depth. The downslope component of the dry weight and the frictional resistance to sliding for dry sand was calculated for various slope gradients as in Figure 31. Then, six inches of ground water was assumed to be present and the frictional resistance to sliding was recalculated taking into account the uplift of the ground water. The results of these calculations are shown in Figure 32. Note that in a dry condition, sliding will occur when the slope gradient exceeds 70 percent. With six inches of ground water, the soil will slide when the slope gradient exceeds 65 percent. Next, assume a dry sand layer only two feet thick that weighs 100 pounds per foot of depth. Again, assume six inches of ground water and recalculate the downslope component of the soil weight and the frictional resistance to sliding with, and without, the ground water. These results are shown in Figure 33. Note that with six inches of ground water, the soil will slide when the slope gradient exceeds 57 percent.

These examples demonstrate that the thinner soil mantle has a greater potential for sliding under the same ground water conditions than a thicker soil mantle. The six inches of ground water is a greater proportion of the total soil thickness for the two-foot soil than for the five-foot soil, and the ratio of uplift to frictional resistance is greater for the two-foot soil. A pure sand was used in these examples for the sake of simplicity but the principles still apply to soils that contain varying amounts of silt and clay together with sand.

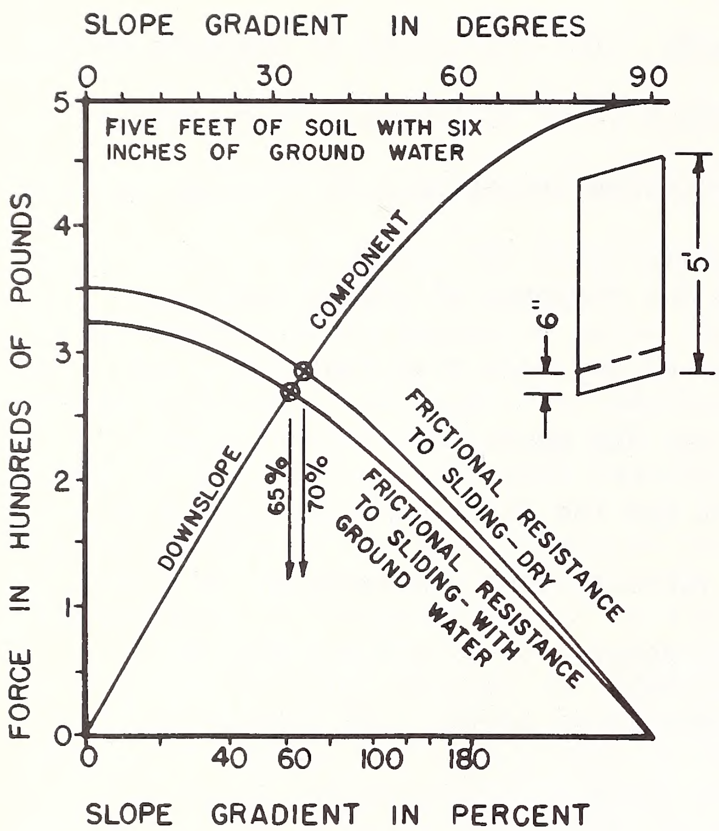


Figure 32. Five feet of soil with six inches of ground water will slide when the slope exceeds 65%.

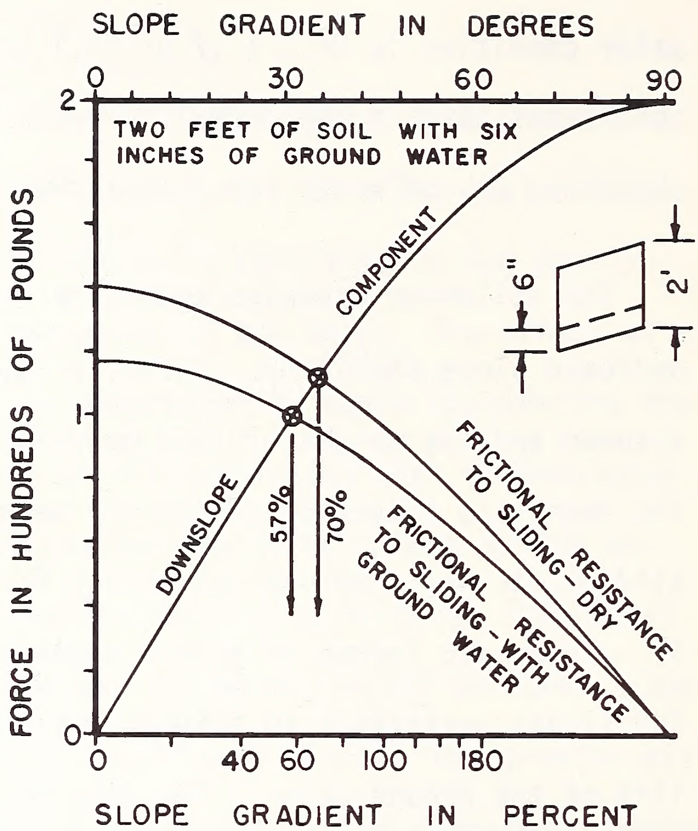


Figure 33. Two feet of soil with six inches of ground water will slide when the slope exceeds 57%.

Seepage Force

There is still another way that ground water contributes to slope instability, and that is the so-called "seepage force" of ground water as it moves downslope. The seepage force is the drag force that moving water exerts on each individual soil particle in its path. The seepage force, therefore, contributes to the driving force that tends to move masses of soil downslope. The concept of the seepage force may be visualized by noting how easily portions of a coarse-textured soil may be dislodged from a road cut bank when the soil is conducting a relatively high volume of ground water.

Tree Roots

The effect of tree root strength on slope stability is not fully understood and is the subject of research studies by the Forest Service and various universities. Preliminary results of these studies indicate that living tree roots

help maintain slope stability. Reports by the Forest Service from southeast Alaska indicate that the number of landslides from cut-over areas increases within 3 to 5 years after logging. This increase is attributed to a reduction in soil shear strength caused by the decay of tree roots following logging. The presence of living tree roots to anchor shallow soils to the underlying subsoil (Figure 34) appears to be particularly important in small drainages where winter storms can cause the ground water level to rise sharply (Swanston, 1970). Similar correlations between the number of landslides following timber cutting and steep slopes with heavy winter rainfall have been noted in other parts of the United States and other countries (Gray). Figures 35 and 36 show typical slope failures that frequently originate within clearcut areas in shallow depressions on steep side slopes. Figure 37 is a stereogram that shows a number of failures on clearcut slopes that have not been roaded.

Figure 34 (left). This illustrates how tree roots act to hold shallow soil to fractured bedrock.

Figures 35 and 36 (below). These photographs show shallow landslides that originate on clearcut areas. They often occur in small drainages where ground water may accumulate.

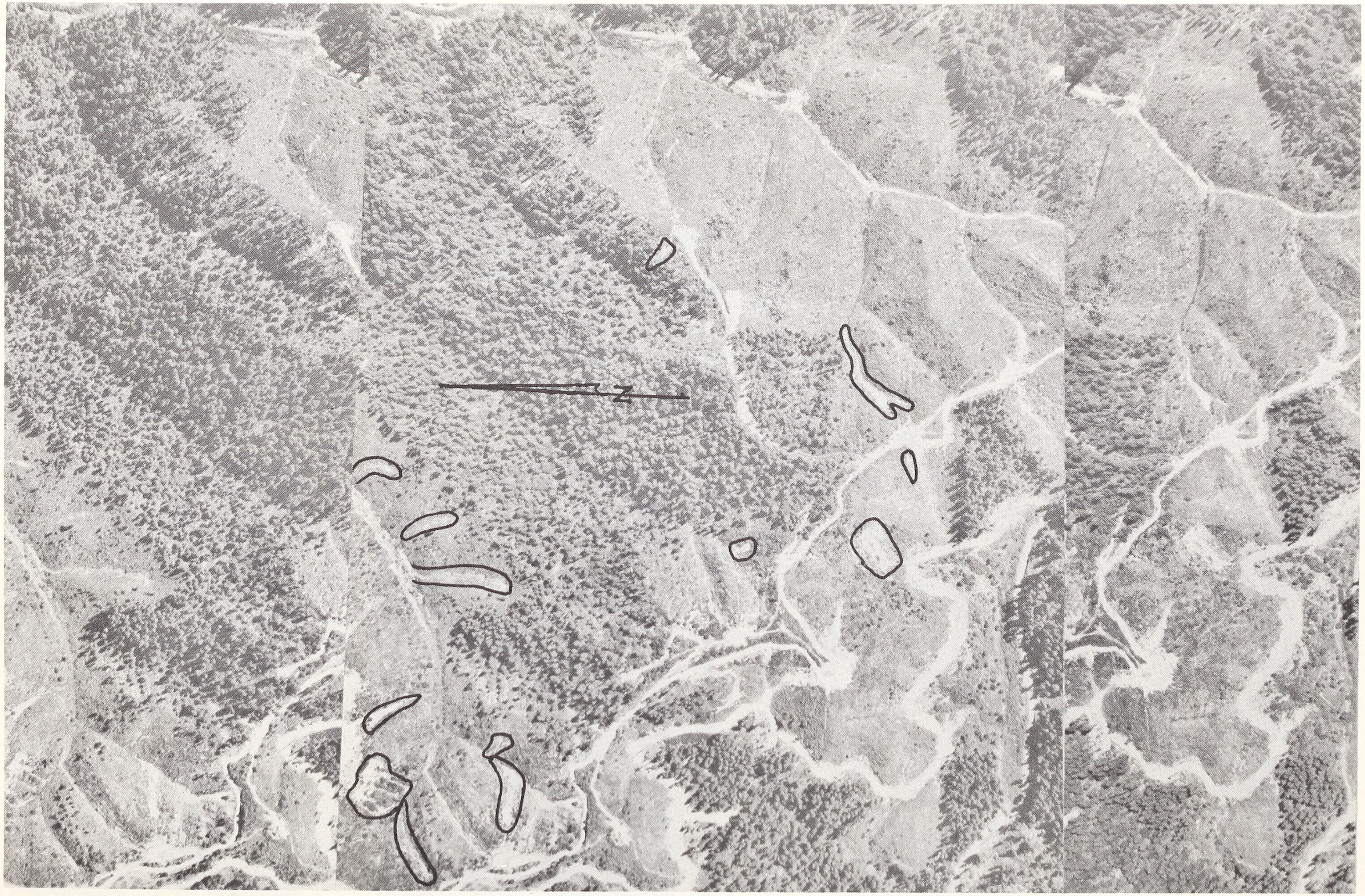


Figure 37. This stereogram shows slope failures that have originated on clearcut areas. The failures outlined in black are not associated with roads.

All studies indicate that if the soils, topography, and vegetation show that an area with mature timber presently has marginal slope stability, then serious consideration should be given to the effect that removal of this timber will have on future slope stability.

Types of Slope Failures

Slope failures include all mass soil movements on (1) man-made slopes such as road cuts and fills, or (2) natural slopes in clearcut areas or undisturbed forest. A classification of slope failure is useful because it provides a common terminology and it offers clues to the type of slope stability problem that is likely to be encountered for a given soil, geologic material, and topography. For example, it has been shown that types of slope and road failures are remarkably consistent with soils, geologic material, and topography. Fast moving avalanches develop in shallow, coarse-textured soils on steep hillsides, and large, rotational slumps occur in deep, saturated soils on gentle to moderate slopes. A survey of road failures over an 18-month period in the Eugene District of the Bureau of Land Management showed that 71% of the road failures in bedded sediments occurred on slopes over 60%, as compared to only 34% of the road failures in volcanic materials on slopes over 60%. The same survey showed that 66% of the road failures in bedded sediments were cut slope failures as compared to 91% in volcanic materials. The following sections will help explain why certain types of slope and road failures are correlated with soils, geologic material, and topography.

1. Rockslides

Rockslides most commonly originate in bedded sediments such as massive sandstone whose beds are undercut by stream erosion or road excavation. Stability is maintained by the competence of the rock and by the frictional

resistance to sliding along the bedding planes; these factors are particularly important where the bedding planes dip downslope toward a road or stream. Rockslides occur suddenly, slide with great speed, and sometimes extend across the valley bottom. Slide debris consists of fractured rock and may include some exceptionally large blocks. Rockslides can range in size from the 40,000,000 cubic yard Madison River slide of 1959 in Montana, that killed 23 people, to the 80,000 cubic yard Camp Creek slide in Coos Bay of 1970 (Figure 38). The Cow Creek slide shown at point B in Figure 23 is a rockslide that occurred in the Dothan formation along a fault zone. Figure 39 shows the deposition of fractured rock and the displacement of the road, both vertically and laterally. This particular slide has a potential for further movement as evidenced by cracks in the slopes on the downstream margin of the slide. Road locations through areas with a potential for rockslides should be examined by specialists who can evaluate the competence of the rock and determine the dip of the bedding planes.

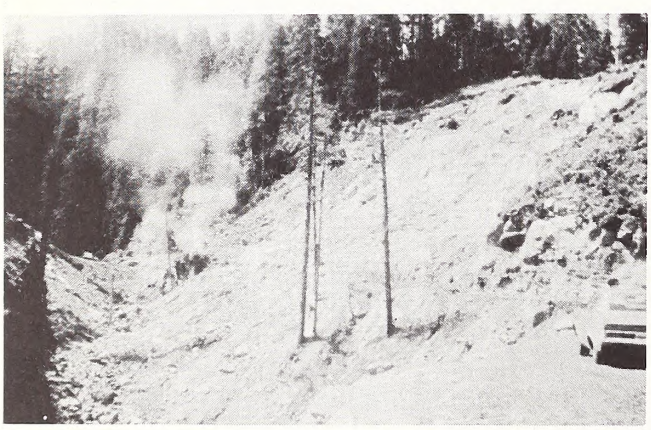


Figure 38. A rockslide in bedded sedimentary material

Figure 39. A photo of the rock-slide illustrated at point B in Figure 23. Note how the shifting rock is lifting the road and moving it to the right towards Cow Creek

2. Debris Avalanches and Debris Flows

These two closely related types of slope failures usually originate on shallow soils relatively low in clay content on steep (>65%) slopes (Figures 40 and 41). In southeast Alaska, the Forest Service has found that debris avalanches develop on slopes greater than 65 percent on shallow, gravelly soils and that this type of slope failure is especially frequent on slopes over 75 percent (Swanston, 1969 and 1970). An excellent description of debris avalanches and flows is given in Bailey, parts of which are quoted below:

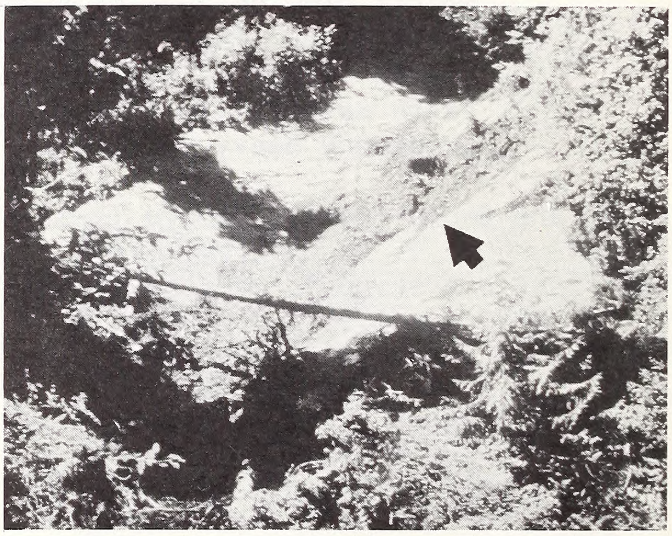
> "Debris avalanches are the rapid downslope flowage of masses of incoherent soil, rock, and forest debris with varying water content. More specifically, they are shallow landslides resulting from frictional failure along a slip surface essentially parallel to the topographic surface, formed where the accumulated stresses exceed the resistance to shear. The detached soil mantle slides downslope above an impermeable boundary within the loose debris or at the unweathered bedrock surface and forms a disarranged deposit at the base. Downslope, a debris avalanche frequently becomes a debris flow because of substantial increases in water content ... They are caused most frequently when a sudden influx of water reduces the shear strength of earth material on a steep slope, and they typically accompany heavy rainfall."

There are two situations where these types of slope failure are most common. The first situation is an area of the bedded sediments where stream development and geologic erosion have formed high ridges with long slopes, and steep, V-shaped drainages. The gradient of many of these streams increases quite sharply from the main stream to the ridge, and erosion has created headwalls in the upper reaches. The headwall region is often the junction for ephemeral stream channels which begin at the ridgetop. This leads to a quick rise in ground water levels during winter rains. Past debris avalanches may have scoured round-bottomed chutes, or troughs, into the relatively hard bedrock (Figure 42). The headwall region is covered with only a shallow soil mantle of precarious stability, and it may show exposed bedrock often dark with ground water seepage (Figure 43).

Figure 40 (left) and Figure 41 (above). These are two examples of debris avalanches in shallow soils on steep slopes.

Figure 42 (left). Frequent debris avalanches may create round-bottomed chutes.

Figure 43 (below). The arrow shows loose material, dark with ground water.



The second situation with a high potential for debris avalanches and flows is caused by excavated material sidecast onto slopes greater than 65 percent. The sidecast material next to the slope maintains stability through frictional resistance to sliding and through support by brush and stumps. As more material is sidecast, the brush and stumps are buried and stability is maintained

solely by frictional resistance to sliding. Since there is very little bonding of this material to the natural slope, the entire slope is said to be overloaded. It is quite common for road fills on steep, overloaded slopes to fail as debris avalanches and flows as soon as the winter rains saturate this unconsolidated material. Under these circumstances the road fill together with a portion of the underlying natural slope forms the debris avalanche (Figure 44).

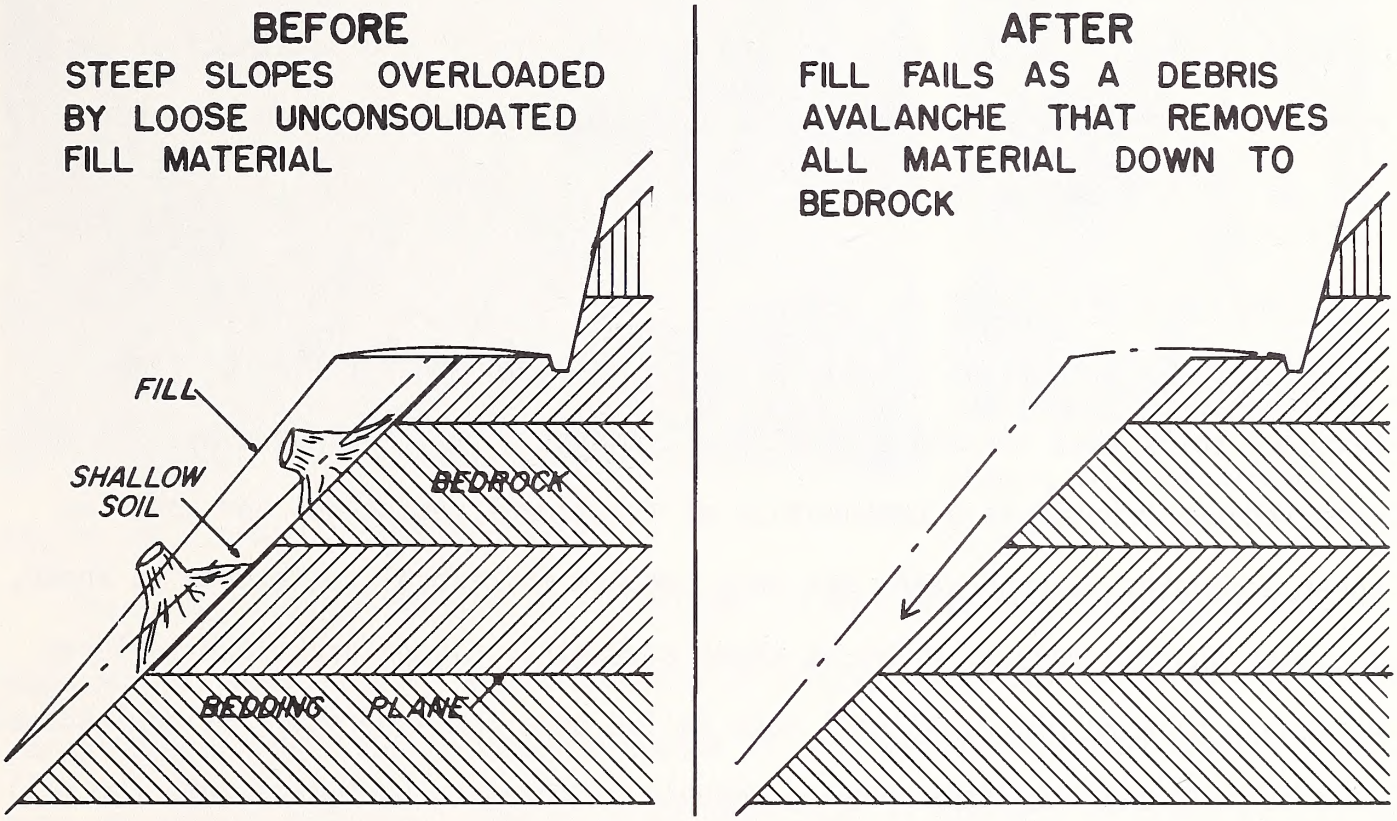


Figure 44. Relationship between overloaded slopes and debris avalanches

Debris avalanches and debris flows occur suddenly, often with little advance warning. There is practically nothing that can be done to stabilize a slope which shows signs of an impending debris avalanche. The best possible technique that can be used to prevent these types of slope failures is to avoid those areas with a high potential for debris avalanches and to avoid overloading steep slopes with excessive sidecast. Foresters and engineers should learn the vegetative and soil indicators of this type of unstable terrain, especially for those areas that high seasonal ground water levels.

If unstable terrain must be crossed by roads, then radical changes in road grade and road width should be made to minimize site disturbance. End-hauling of excavated material may be necessary to keep overloading of unstable slopes to an absolute minimum. The location of safe disposal sites for end-hauled material may be a serious problem in steep terrain with sharp ridges. Selection of these sites will require just as much attention to the principles of slope stability as the location and construction of the remainder of the road. Some specific techniques for slope stabilization and road construction will be given later in this guide.

3. Slumps and Earthflows

Slumps and earthflows usually occur in deep, moderately fine or fine-textured soils that contain a significant amount of silt and/or clay. In this case, shear strength is a combination of frictional resistance and cohesive shear strength. Ground water not only reduces frictional resistance to shear, but also sharply reduces cohesive shear strength. Slumps are slope failures where one or more blocks of soil have failed on a hemispherical, or bowl-shaped, slip surface and they show varying amounts of rotation backwards into the hill in addition to downslope movement (Figure 45). The lower part of the slump is displaced upward and outward like a bulbous toe. The rotation of the slump block usually leaves a depression at the base of the main scarp. If this depression fills with water during the rainy season, then this feature is known as a sag pond. Figure 22 shows a classic example of a slump; note the sag pond (dry at the time of the photo) and the bulging toe. Another feature of large slumps is the "hummocky" terrain, composed of many depressions and uneven ground that is the result of continued earthflow after the original slump. Depressions and sag ponds allow winter rains to enter the ground water reservoir, reduce the

stability of the toe of the slump, and promote further downslope movement of the toe. The mature timber that usually covers old slumps often contains "<u>jackstrawed</u>" or "<u>crazy</u>" trees that lean at many different angles within the stand and indicate unstable soils and actively moving slopes (Figure 46).

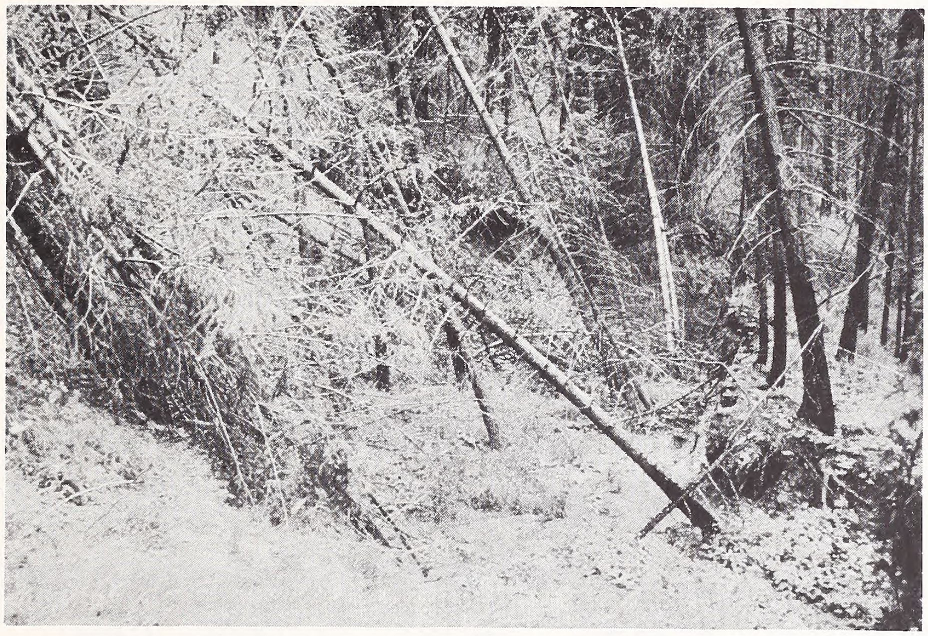


Figure 45. Rotation of slump block

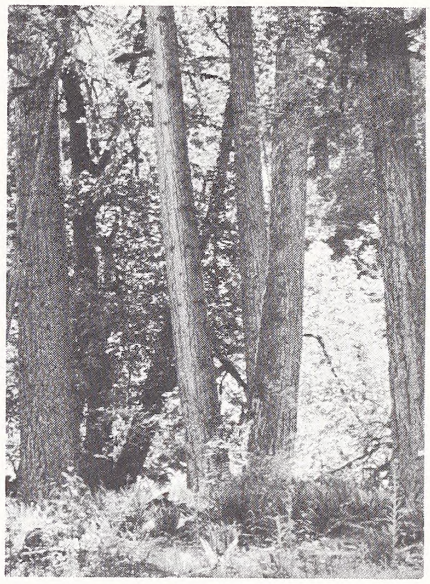
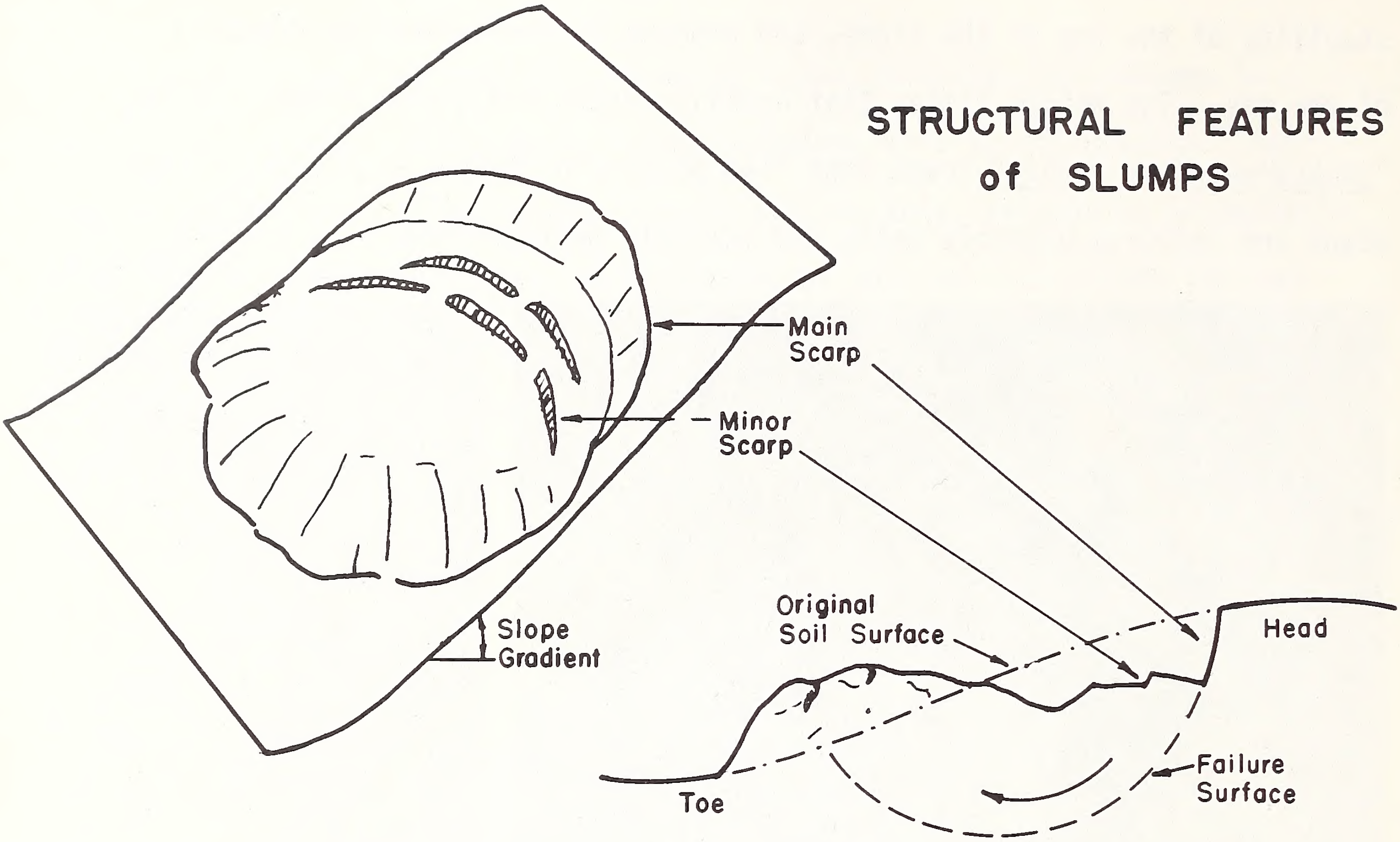
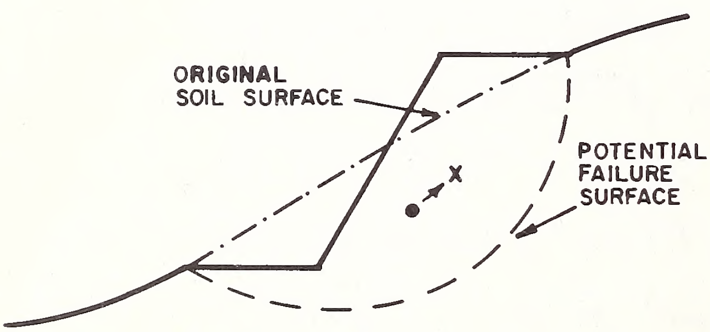


Figure 46. Jackstrawed trees indicate unstable soil

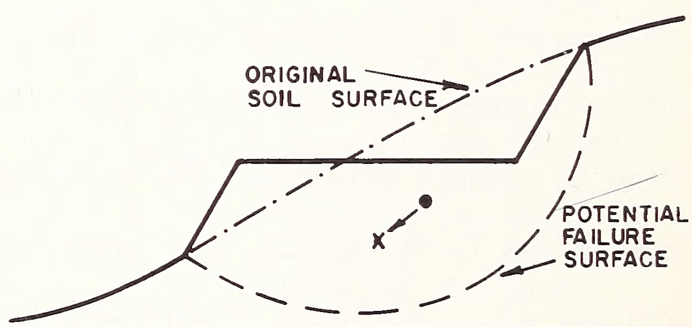
There are several factors of rotational slumps that need to be examined in some detail to understand how to prevent or remedy this type of slope failure: those factors that tend to cause rotation of a block of soil, and those that tend to prevent rotation. The block of soil that is subject to slumping can be considered to be resting on a potential failure surface of hemispherical shape (Figure 47). The block is most stable when its center of gravity is at its lowest position on this failure surface. When the block fails, its center of gravity is shifted to a lower, more stable position as a result of the failure. Added weight, such as a road fill, at the head of a slump shifts the center of gravity of the block to a higher, more unstable position and tends to increase the potential for rotation. Similarly, removing weight from the toe of the slump, as in excavating for a road, also shifts the center of gravity of the block to a higher position on the failure surface. Therefore, loading the



HOW ROAD CONSTRUCTION ACROSS SHORT SLOPES CAN AFFECT THE POTENTIAL FOR A BLOCK OF SOIL TO FAIL BY SLUMPING



LOADING THE HEAD AND/OR UNLOADING THE TOE SHIFTS THE CENTER OF GRAVITY UPWARD AND <u>INCREASES</u> THE POTENTIAL FOR SLUMPING.



LOADING THE TOE AND/OR UNLOADING THE HEAD SHIFTS THE CENTER OF GRAVITY DOWNWARD AND <u>DECREASES</u> THE POTENTIAL FOR SLUMPING.

● = ORIGINAL CENTER OF GRAVITY OF SOIL BLOCK.
X = CENTER OF GRAVITY OF SOIL BLOCK AFTER CUT OR FILL HAS BEEN COMPLETED.

Figure 47. Structural features of slumps and the effect of cutting and filling on the stability of short slopes.

head of a slump and/or unloading the toe will increase the potential for further slumping on short slopes. The chance of slumping can be reduced by shifting the center of gravity to a lower position by following the rule: "Unload the head and load the toe."

Excavation for roads on relatively long slopes may increase the potential for slumping at two locations as shown in Figure 48 - one immediately above the road and the other under the road fill. Excavation may remove enough support to cause a slump above the road on a long slope and sidecast may overload the slope sufficiently to cause a slump of the fill material. Endhauling of excavated material may be necessary for roads built across long slopes in deep, fine-textured soils. Also, "benching" of the slope above the road may be necessary to reduce the potential for cut slopes to slump.

Assuming that it is absolutely necessary to locate a road through terrain with a potential for slumping, there are several techniques that may be considered to prevent slumps and earthflows. Improved surface drainage is one of the cheapest and most effective techniques and one that is often overlooked. Sag ponds and depressions can be connected to the nearest stream channel with ditches excavated by bulldozer or ditching powder. Figure 49 shows the theoretical effect on the ground water reservoir of a surface drainage project. Improved surface drainage removes water quickly, lowers the ground water level, and helps stabilize the slump.

Another technique is to lower the ground water level by means of perforated pipe that is augered into the slope at a slight upward angle. These drains are usually installed in road cutbanks to stabilize areas above an existing road, or below roads to stabilize fills. Installation of perforated pipe is relatively

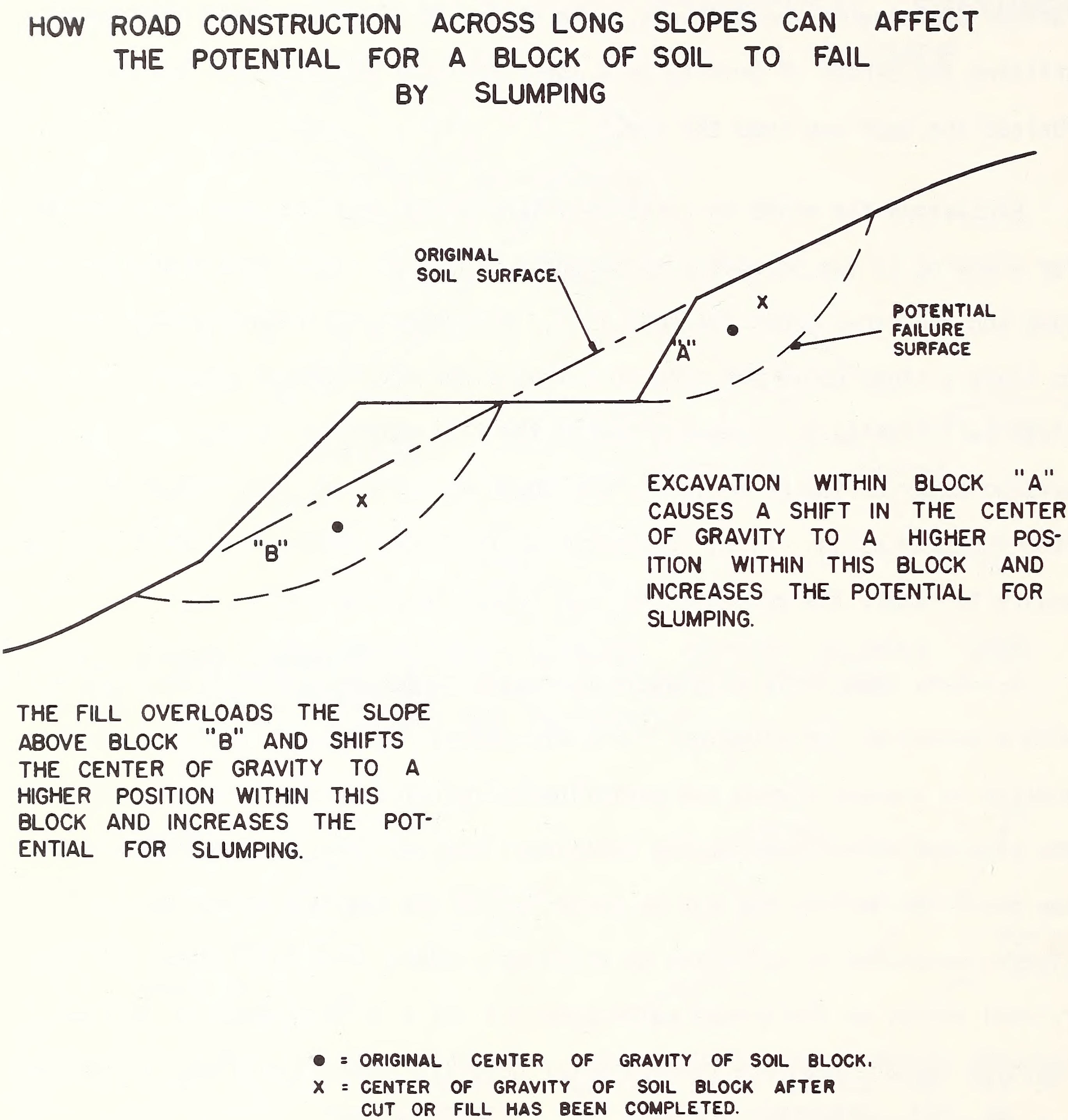
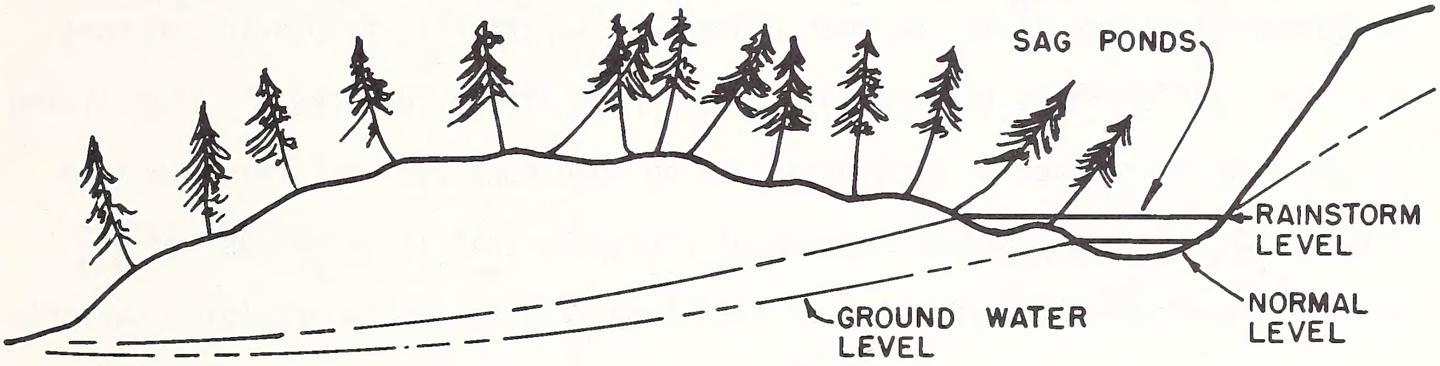


Figure 48. The effect of cutting and filling on the stability of long slopes.

HOW DRAINAGE OF SURFACE WATER CAN INCREASE SLOPE STABILITY



SAG PONDS ADD WATER TO THE GROUND WATER RESERVOIR AND INCREASE THE POTENTIAL FOR FURTHER SLUMPING.

DITCHES CAN DRAIN SAG PONDS, LOWER THE GROUND WATER LEVEL, AND INCREASE SLOPE STABILITY.

Figure 49. Drainage of surface water can increase slope stability by lowering the ground water level

expensive and there is a risk that slight shifts in the slump mass may render the pipe ineffective. In addition, periodic cleaning of these pipes is necessary to prevent blockage of the pipe by algae, soil, or iron deposits.

A third technique for stabilization of existing slumps and the prevention of potential slumps is to use rock riprap, or buttresses, to provide support for road cuts or fills (Figure 50). Heavy rock riprap replaces the stabilizing weight that is removed by excavation during road construction (refer back to Figures 47 and 48). Another feature of riprap is that it is porous and it allows ground water to drain out of the slump material while providing support.

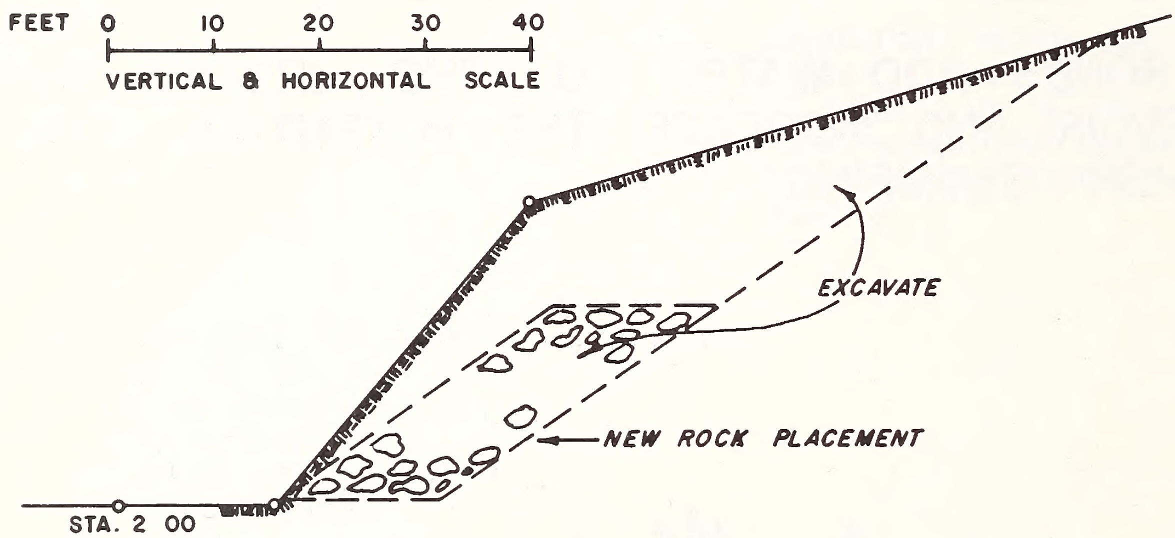


Figure 50. A sample design for a rock buttress to provide support for a failing slope.

A fourth technique is installation of an interceptor drain to collect ground water moving laterally downslope and under the road. A backhoe can be used to install interceptor drains in the ditch along an existing road. Figure 51 shows a sample installation.

Finally, compaction of fills may be used to increase the stability of excavated material by increasing the density, reducing the pore space, and thereby reducing the adverse effect of ground water.

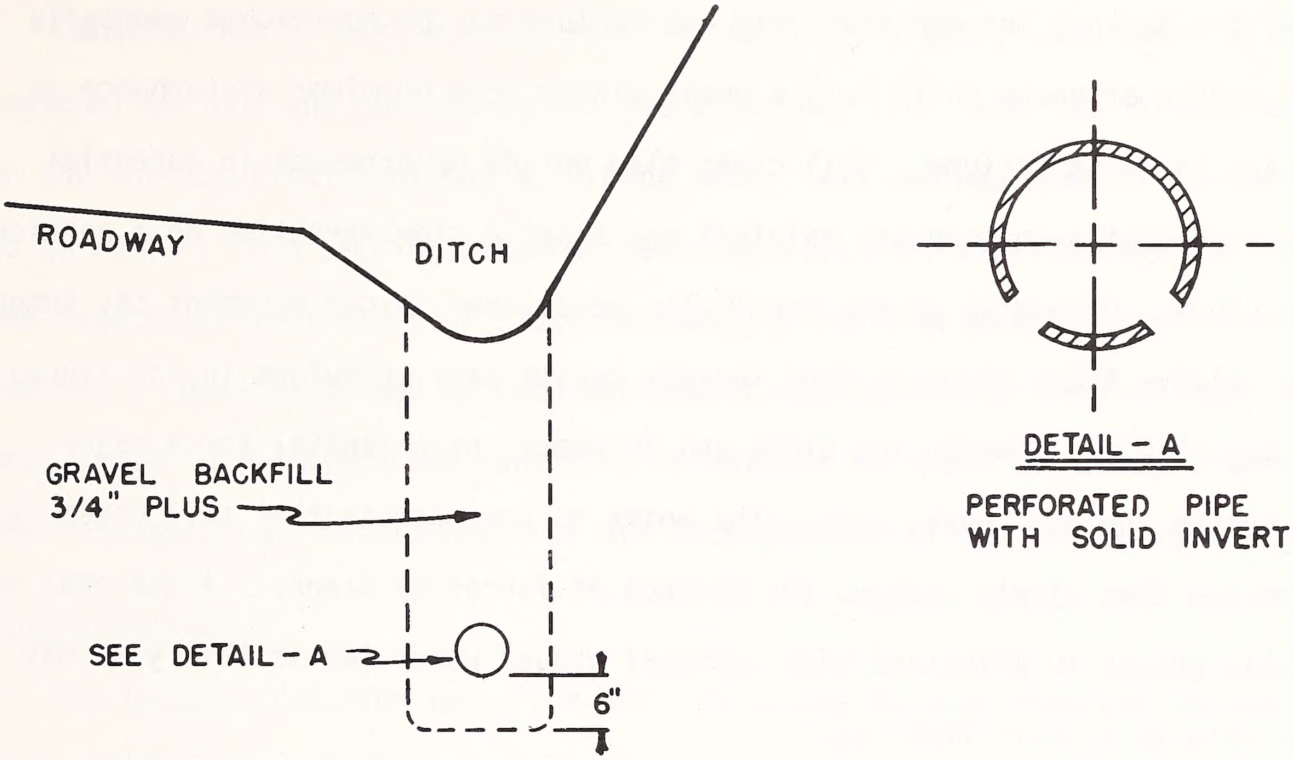


Figure 51. A sample design for an interceptor drain

4. Soil Creep

The foregoing types of slope failures are relatively fast moving rock-slides, avalanches, and slumps. Many of these slope failures, particularly debris avalanches and slumps, may be preceded and followed by soil creep that is a relatively slow moving type of slope failure. Soil creep may be a continuous movement on the order of less than one foot per decade (Bailey). The indicators of soil creep may be subtle, but foresters and engineers must be aware of the significance of this type of slope failure. Soil creep at any moment may be immeasurable but when the effect is cumulated over many years, soil creep can create stresses within the soil mantle that may approach the limit of frictional resistance to sliding and/or the cohesive shear strength along a potential slump failure surface.

Soil creep is particularly treacherous in conjunction with debris avalanches because the balance between stability and failure may be approached gradually over a number of years until only a heavy winter rain or minor disturbance is necessary to cause failure. Soil creep also builds up stresses in potential slumps such that even moderate rainfall may start a slow earthflow on a portion of the slope. Depending on the particular conditions, minor movement may temporarily relieve these stresses (and thereby create sags or bulges in the slope), or it may slightly steepen the slope and increase the potential for a major slump during the next heavy rain. The point to remember is that soil creep is the process that slowly changes the balance of forces on slopes. Areas that may be stable enough to withstand high seasonal ground water levels this year may not be able to 5 years from now.

CONSTRUCTION OF STABLE ROADS

Construction of stable roads requires not only a basic understanding of regional geology and soil mechanics but also specific, detailed information on the characteristics of soils, ground water, and geology where the road is to be built. This section presents techniques on road location and the soil and vegetative indicators of slope instability and high ground water levels. Personnel from the Bureau of Land Management and the Forest Service have been interviewed concerning road construction methods on specific geologic materials. Their comments and recommendations are incorporated in the following sections.

Bedded Sediments

The bedded sediments vary from soft siltstone to hard, massive sandstone. These different geologic materials, together with geologic processes and the effect of climate acting over long periods of time determine slope gradient, soil, and the rate of erosion. These factors also determine the particular type of slope stability problem that is likely to be encountered. There are four slope stability problems that are associated with distinctive sites within the bedded sediments. The first two stability problems are found on sandstone bedrock and will be designated as Types I and II. The third and fourth problems are found on deeply weathered siltstone and the sandstone-igneous rock contact.

1. Sandstone - Type I

Type I slope stability problems are found on the Tyee and Yamhill formations. Type I sites are characterized by steep slopes with sharp ridges that may show a uniform slope gradient from near the ridgetop to the valley bottom. The landscape is sharply dissected by numerous stream channels; these channels may become extremely steep as they approach the ridgetop. Headwalls (bowl-shaped areas with slope gradients often 100 percent or greater) may be present in the upper reaches of the drainage (see Figure 41). The headwall is usually

the junction for several emphemeral streams that can cause sharp rises in the ground water levels in the headwall region during winter storms. It is quite common to note ground water seepage on exposed bedrock in the headwall even during the summer. Figure 52 shows a block diagram that illustrates the features of Type I sites. This area was taken from the upper Smith River as shown on the topographic map in Figure 53.

There are two soil series commonly associated with Type I sites: the 564 soil over hard bedrock is considered to be unstable on slopes greater than 70 percent, and the 64 soil over fractured bedrock is considered to be unstable on slopes over 80 percent.

Debris avalanches and debris slides are the most common slope failure on Type I sites, and the headwall region is the most likely point of origin for these failures. Construction of roads through headwalls will cause unavoidable sidecast. The probability is high for even minimum amounts of sidecast to overload slopes with marginal stability and to cause these slopes to fail (Figures 54 and 55). Observers often comment on the stability of full bench roads that were built through headwalls without realizing that debris avalanches may have occurred during construction before any traffic moved over the road. Figures 56 and 57 show the potential for damage to life and property from the fast moving and very destructive debris avalanche and debris flow.

Figure 53 shows the steep, highly dissected terrain that is distinctive of Type I sites in western Oregon. Small scale topographic maps (such as the Western United States, 1:250,000 scale) may be used with Figure 2 to outline areas within the bedded sediments that are likely to have Type I slope stability problems. Some of these areas are: tributaries on the north side of the Alsea

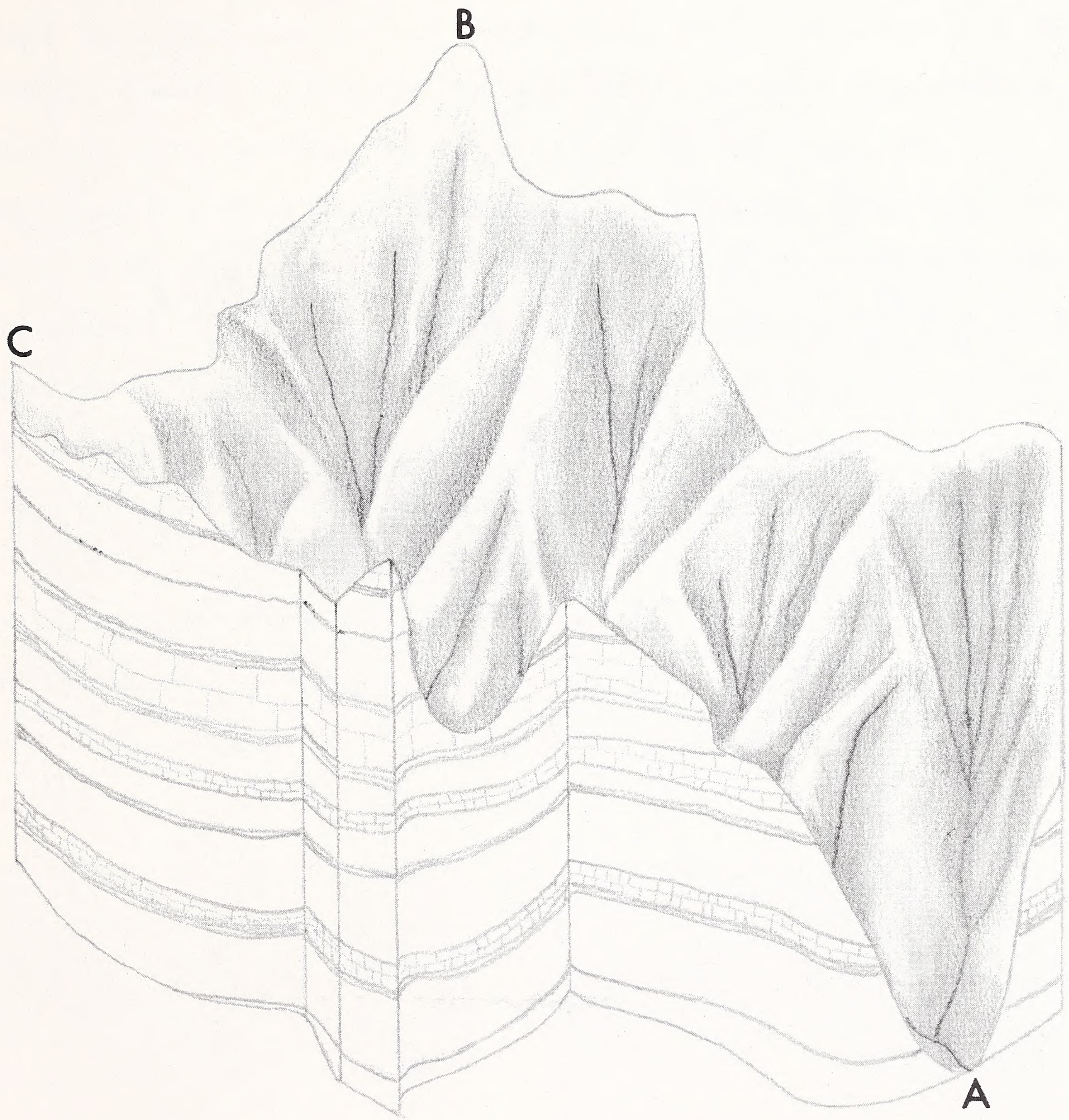


Figure 52. A block diagram of Type I sites, the steep, highly dissected terrain with sandstone bedrock where debris avalanches are the most common kind of slope failure. This diagram was made from the topographic map of the drainage basin outlined in Figure 53. The mouth of the basin is at point A, and two high points are identified as points B and C. The vertical scale of the block diagram is greatly exaggerated. Note the steep headwall areas below point B and above point A. Compare with Figure 65.

Figure 53. A topographic map of the steep terrain with sandstone bedrock where debris avalanches are the most common type of slope failure. The basin outlined in black is shown in the block diagram in Figure 52. Points A, B, and C may be used for orientation. Note the characteristic drainage pattern. Compare with Figure 66.

River from Drift Creek to Fall Creek; the upper portion of Green River, Five Rivers and Lobster Creek (all in the Alsea drainage); the Siuslaw River from Sweet Creek (near Point Terrace) upstream past Haight Creek, including Lake Creek to Blachly, and Wildcat Creek past Walton; the Smith River drainage from just below the North Fork to just beyond the South Fork; both sides of the Umpqua River from Dean Creek upstream to Scottsburg; the upper portions of the north side Umpqua River tributaries from Weatherly Creek to Big Tom Folley Creek; the central portion of the Yamhill formation that includes the upper reaches of Lake Creek, Camp Creek, Rodder Creek, and Mehl Creek; the West Fork of the Millicoma River above Alleghany east to Loon Lake; the East Fork of the Millicoma River from below Marlow Creek, and excluding the upper portions of Glen Creek and Matson Creek; the South Fork of the Coos River above Dellwood, including the Williams River and the upper portions of Fall Creek, and Bottom Creek east to Green Peak; the upper reaches of the Coquille River east of the 124th meridian south to Middle Creek; and the East Fork of the Coquille River north and east of Sitkum.

Figure 54. A photo of two steep headwalls where sidecast material from roads can cause debris avalanches

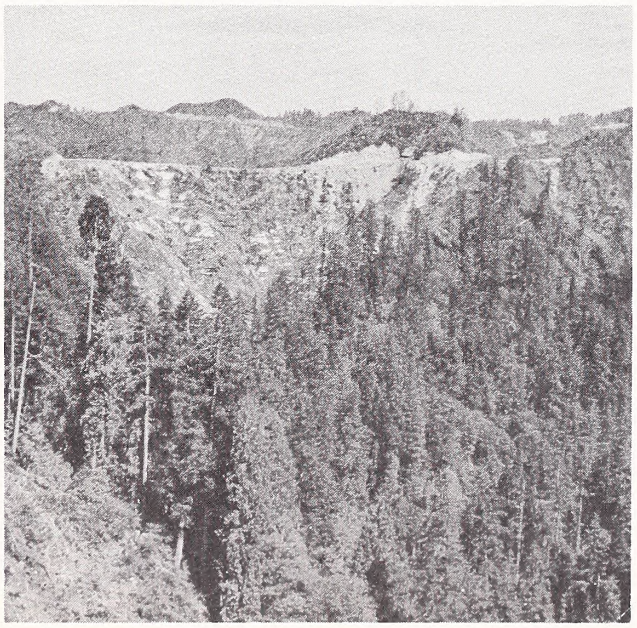


Figure 55. A view of several headwalls with extremely steep slopes and thin soils

Figure 56. The result of a debris avalanche from a road fill in a headwall in sandstone material

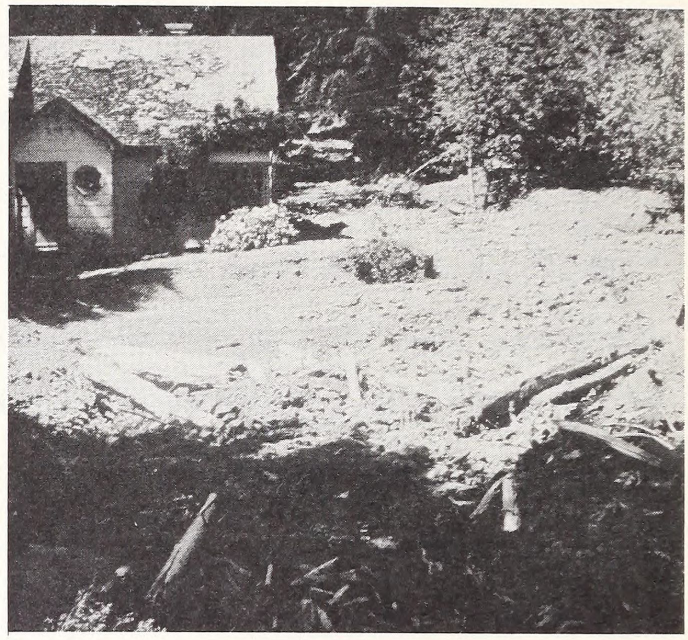


Figure 57. A debris flow came down the stream channel just to the right of the house

There are certain indicators of unstable slopes for these Type I sites that may be used during road location.

Pistol-butted trees (Figure 58). These trees were tipped downslope while small as a result of sliding soil or debris, or as a result of active soil creep. As the tree grew, the top regained a vertical posture. Note, pistol-butted trees may indicate slope instability on other areas throughout western Oregon, but it should be kept in mind that deep, heavy snowpack at high elevations, such as the High Cascades, may also cause this same deformation.

Tipped trees (Figure 59). These trees have a sharp angle in the stem. This indicates that the tree grew straight for a number of years until a small shift in the soil tipped the tree and the angled stem is the result of the recovery of the vertical attitude.

Tension cracks (Figure 60). Soil creep builds up stresses in the soil mantle which are sometimes relieved by tension cracks. These features may be hidden by vegetation but they definitely indicate active soil movement.

Figure 58 (left). Pistol-butted trees may be used as an indicator of active soil movement when the trees were young

Figure 59. Tipped trees have a sharp angle in the stem.

Figure 60. Tension cracks may be hard to find, but they indicate active soil movement

Techniques for proper road location on Type I sites include:

<u>Avoid headwall regions</u>. Ridgetop locations are preferred rather than crossing through headwall regions.

<u>Rolling the road grade</u>. Avoid headwalls or other unstable areas by rolling the road grade. Short segments of up to 20% adverse and 20% favorable may be included.

Consider the following construction techniques when roads must be constructed across long, steep slopes or above headwall regions where sidecast must be held to a minimum:

<u>Reduce the road width</u>. This may require small tractors with narrower blades (D-6, for example) for construction. A U-shaped blade is reported to result in less sidecast than a straight blade, possibly because of better control of loose material.

<u>Endhaul material</u>. Endhauling excavated material away from the steepest slopes may be required to avoid overloading the lower slopes.

<u>Fill saddles</u>. Narrow saddles may be used to hold endhauled material by first excavating narrow bench roads below, and on each side of the saddle. The saddle may then be flattened and the loose material that rolls downslope will be caught by the benches. Endhauled material may be compacted on the flattened ridge to build up the grade (Figures 61 and 62).

<u>Select safe disposal sites</u>. Disposal sites for endhauled material should be chosen with care to avoid overloading a natural bench or spur ridge and causing slope failure (Figure 63). The closest safe disposal site

may be a long distance from the construction site, but the additional hauling costs must be weighed against the damage caused by failure of a closer disposal site with a higher probability of failure.

Stream crossings. The stream gradient in many stream crossings in this terrain may be 50 percent or greater on smooth bedrock. In these situations it is necessary to full bench the road and provide a toe catch for the fill material. Figure 64 shows a sample design for such a stream crossing from the Coos Bay District. Also, keep sidecast material to a minimum on the inside of the curve in these stream crossings. Consider endhauling excess material and compacting the fill on each side of the crossing.

Culvert size. Choose a culvert size which will carry the maximum estimated flow volume. The extra size will provide capacity for the unusual storm.

Protect slopes. Culverts must not discharge drainage water onto the base of the fill slope. Culverts should either be designed to carry water on a natural grade for the entire width of the fill or down-spouts should be used to conduct water from the end of shorter culverts down the fill slope to the natural channel.

Figure 61. Endhauled material may be compacted on flattened ridges.

Figure 62. This ridge road has remained stable for two winters.

Figure 63 (left). A disposal site for end-hauled material was located to the left of, and below, the road. Note the cracked and sunken grade.

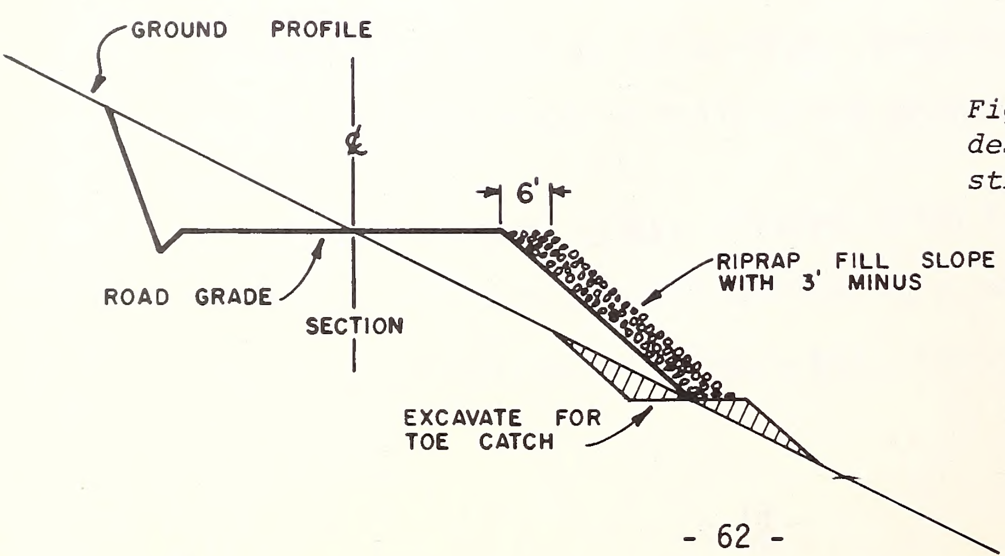


Figure 64 (left). A sample design for crossing a steep stream channel

2. Sandstone - Type II

Type II stability problems are also found on the Tyee and Yamhill formations and Type II sites have slopes whose gradients range from less than 10 percent up to 70 or 80 percent. The longer slopes may be broken by benches, the ridges are rounded, the drainages are fewer, and the slope gradients are more gentle than those on Type I sites. Figure 65 is a block diagram of Type II topography taken from the topographic map shown in Figure 66 (compare with Figures 52 and 53). Headwalls are rare and small patches of exposed bedrock are only occasionally found on the steeper slopes.

The soils on the gentle slopes have developed over many centuries and are deep (often greater than 40 inches) with a clay content as high as 50 to 70 percent. The soils on the steeper slopes may be as deep as 40 inches, but the bedrock is fractured and weathered such that there is a gradual transition from the soil into the massive bedrock. It is these factors of deeper soils, higher clay content, gentler slopes, and a gradual transition to bedrock which makes this terrain more stable than the terrain on Type I sites.

The factors which characterize Type II sites also cause this terrain to have more slump and earthflow types of slope failures. The most unstable portions of Type II sites are the steep, concave slopes at the heads of drainages, the edge of benches, or those locations where ground water tends to accumulate. Road failures frequently involve poorly consolidated or poorly drained road fills, and embankments greater than 12 to 15 feet on any of the red clayey soils such as Honeygrove, Blachly, or Jory. The convex portions of ridges are also susceptible to failure. Here the clayey Honeygrove, Peavine, and Blachly soils on the gently sloped ridgetops change to the more shallow, coarser-textured Digger and Bohannon soils on the 60 to 70 percent side slopes. Soil

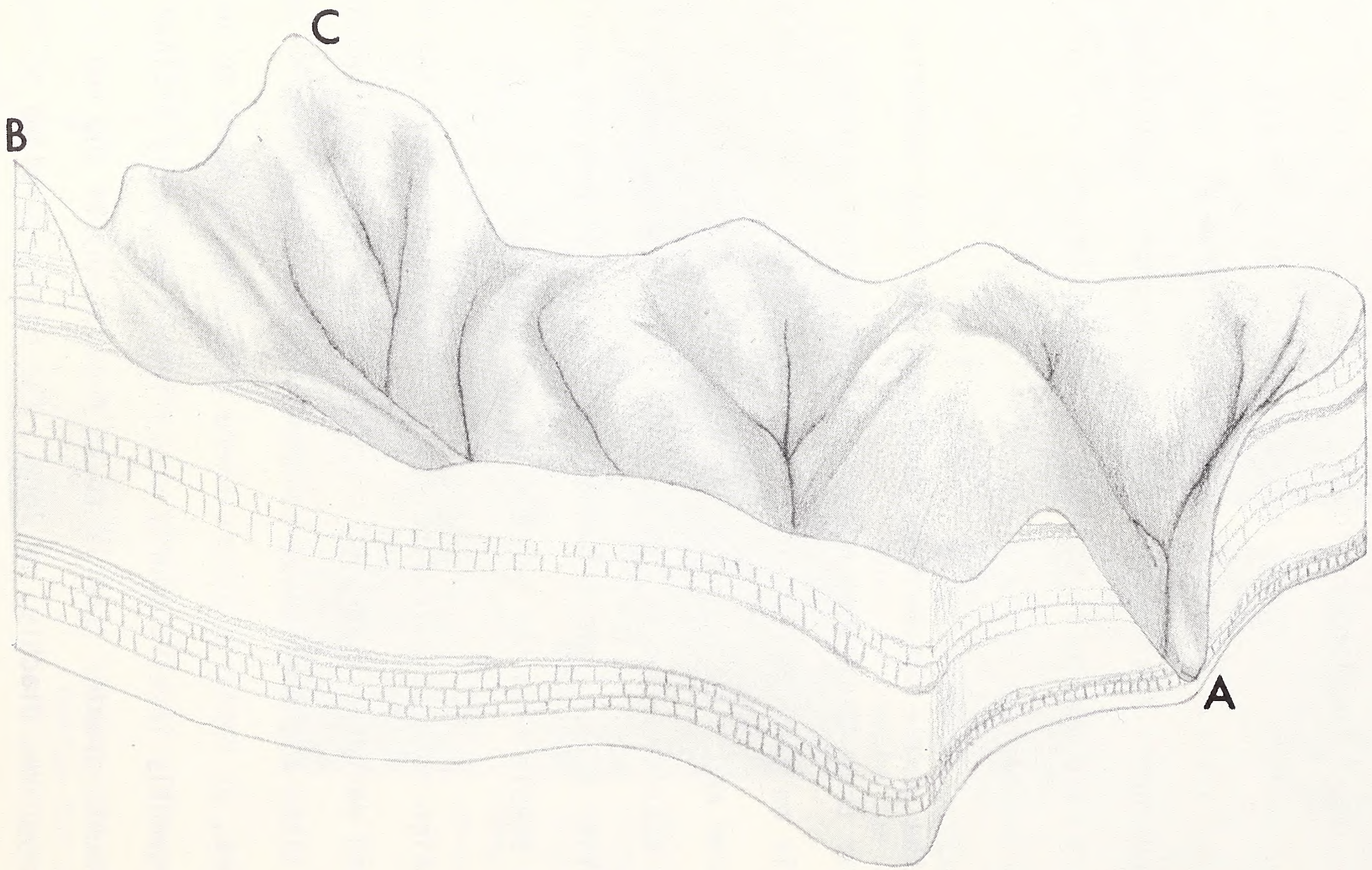


Figure 65. A block diagram of Type II sites. The geologic material is sandstone; the slopes may range from 10% to 80% but the soils are deeper and the ridges are more rounded. Compare with Figure 52. Slumps and earthflows are the most common type of soil failure. This diagram was made from the topographic map of the drainage basin outlined in black on Figure 66. The mouth of the basin is at A, and the high points are at B and C.

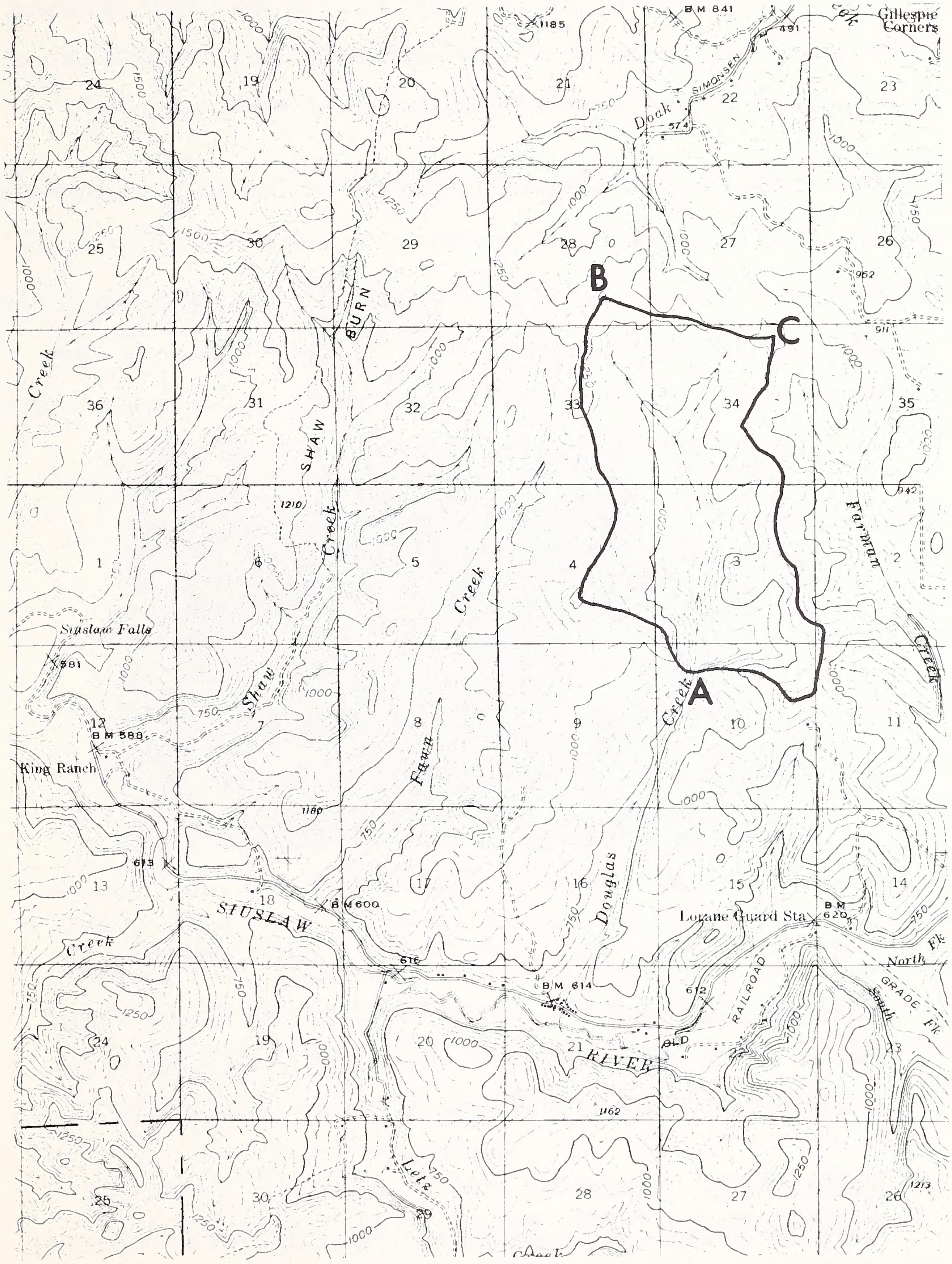


Figure 66. A topographic map of an area with sandstone bedrock, deep soils, and rounded ridge tops. Slumps and earthflows are the most common kind of slope failures. The drainage basin outlined in black is shown in the block diagram of Figure 65. Points A, B and C may be used for orientation. Note the characteristic drainage pattern. Compare with Figure 53.

creep also creates tension within the clayey soils at the convex ridgenose where slopes may only be 50 percent. Excavation for roads at these points of sharp slope convexity sometimes causes failure of the embankment.

Vegetative indicators of unstable portions of the landscape include mature trees that tip or lean as a result of minor earthflow or soil creep on the steeper slopes. Tipped or leaning trees may also be found on poorly drained soils adjacent to the stream channels. Actively moving slopes may show tension cracks or cat steps (Figure 67), particularly on the steeper slopes.

Figure 67. Cat steps, or small scarps, result from slope failures.

Techniques for locating stable roads on Type II sites include:

Avoid steep concave basins. Avoid locating roads through steep, concave basins where stability is questionable, as indicated by vegetation and topography; ridgetop locations are preferred.

Stable benches. Benches may offer an opportunity for location of roads and landings, but these benches should be examined carefully to see that they are supported by rock and are not ancient, weathered slumps with marginal stability.

Avoid cracked soil. Avoid locating a road around convex ridgenoses or below the edge of benches where tension cracks or cat steps indicate a high probability for embankment failure.

Certain design and construction practices should be considered when building roads in this terrain.

Avoid overconstruction. If it is necessary to build a road across steep drainages, avoid overconstruction and endhaul excess material to avoid overloading slopes.

Avoid high cut embankments. The district soil scientist may be able to suggest a maximum height at the ditch line for the particular soil and situation. Twelve to fifteen feet has been suggested as a rule of thumb estimate for maximum height for a cut bank in deep, clayey soils.

Special attention to fills. Fills of clayey material over steep stream crossings may fail if the material is not compacted and if ground water saturates the base of the fill. Fill failures in this wet, clayey material on steep slopes tend to move initially as a slump, then may change into a mud flow down the drainage (see Figure 68). To reduce the chance of fill failures, the following alternatives are suggested:

Compaction. Compact the fill to accepted engineering standards, paying special attention to proper lift thicknesses, moisture content, and foundation conditions.

Drainage design. Design drainage features, where necessary, to control ground water in the base of the fill. For example, consider either a perforated pipe encased in a crushed rock filter (see Figure 51) or a blanket of crushed rock under the entire fill.

Figure 68. Failures of saturated, clayey fills may begin as a slump, then continue as a mud flow.

3. <u>Deep Soils Derived from Siltstone</u>

The Nestucca formation contains considerable siltstone and the stability problem originates in the siltstone that is basically incompetent and easily weathered. Slumps and earthflows, both large and small, are very common when this material is subjected to heavy winter rainfall (as much as 100 inches in the Nestucca River basin). The slopes may exhibit a benchy or hummocky appearance and slopes with gradients as low as 24 percent may be considered to be unstable in deeply weathered siltstone with abundant ground water. Many of the higher ridges in the Nestucca formation are composed of intrusive volcanic rock and the siltstone forms the easily eroded basins bounded by the harder material. Bear Creek drainage, a tributary of the Nestucca River, contains examples of these stability problems (Figure 69).

The Baker Creek area (Figure 70), a tributary of the South Fork of the Coquille River, illustrates these same stability problems in the Otter Point formation. Here, a relatively hard, dark sandstone (Figures 3f and 9) forms the boundary for the basins and the easily weathered siltstone causes slumps and earthflows similar to those in the Nestucca River basin. In Baker Creek, however, the situation is made even worse by the presence of scattered outcrops of serpentine.

Figure 69. Terrain derived from weathered siltstone of the Nestucca formation. Note the hummocky slopes, the large slump in a clearcut area (arrow), and the hydrophytes on the hillside at the right of the photo.

Figure 70. Terrain derived from the Otter Point formation. Note evidence of old slumps, and the recent slump in right foreground.

Figure 71. Benchy, hummocky terrain derived from weathered siltstone. Many of these depressions collect surface water and this causes continued earth movement.

Vegetative and topographic indicators of slope instability are numerous. Large patches of alder, maple, or other hydrophytes[1/] indicate high ground water levels and impeded drainage (see the large patch of alder and big leaf maple in Figure 69). Conifers may be caused to tip or lean by earthflow or soil creep. Slumps cause numerous benches, some of which show sag ponds (Figure 71). Blocks of soil may sag and leave large cracks which gradually fill in with debris and living vegetation. The sharp contours of these features soften in time until these cracks appear as "blind drainages" or sections of stream channel which are blocked at both ends. These cracks collect water, keep the ground water reservoir charged, and contribute to active soil movement.

Techniques for locating stable roads through terrain which has been derived from deeply weathered siltstone include:

> Indicators of ground water. Avoid locating roads through areas where ground water levels are high and where slope stability is likely to be at its worst. Such locations may be indicated by hydrophytes and by tipped or leaning trees.
>
> Consider ridges. Ridgetop locations may be best because ground water drainage is better there. Also, the underlying rock may be exposed which may be more stable road building material than the weathered siltstone.
>
> Adequate reconnaissance. Take pains to scout the terrain away from the proposed road location (on aerial photos and on the ground) to be assured that the line does not run through, or under, an ancient slump whose stability may be upset by road construction. Figure 72 is a stereogram

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1/ Hydrophytes are plants which are associated with wet soils. The particular species which indicate abundant soil moisture should be locally defined because the species may vary from district to district.

of a road location across the bottom of a large, old slump in the Yamhill formation (point A in the stereogram). Sag ponds and depressions are common within the forest from A through B. Much of the area is moving, especially at point C where the ground water level is kept at a high level by sag ponds at B.

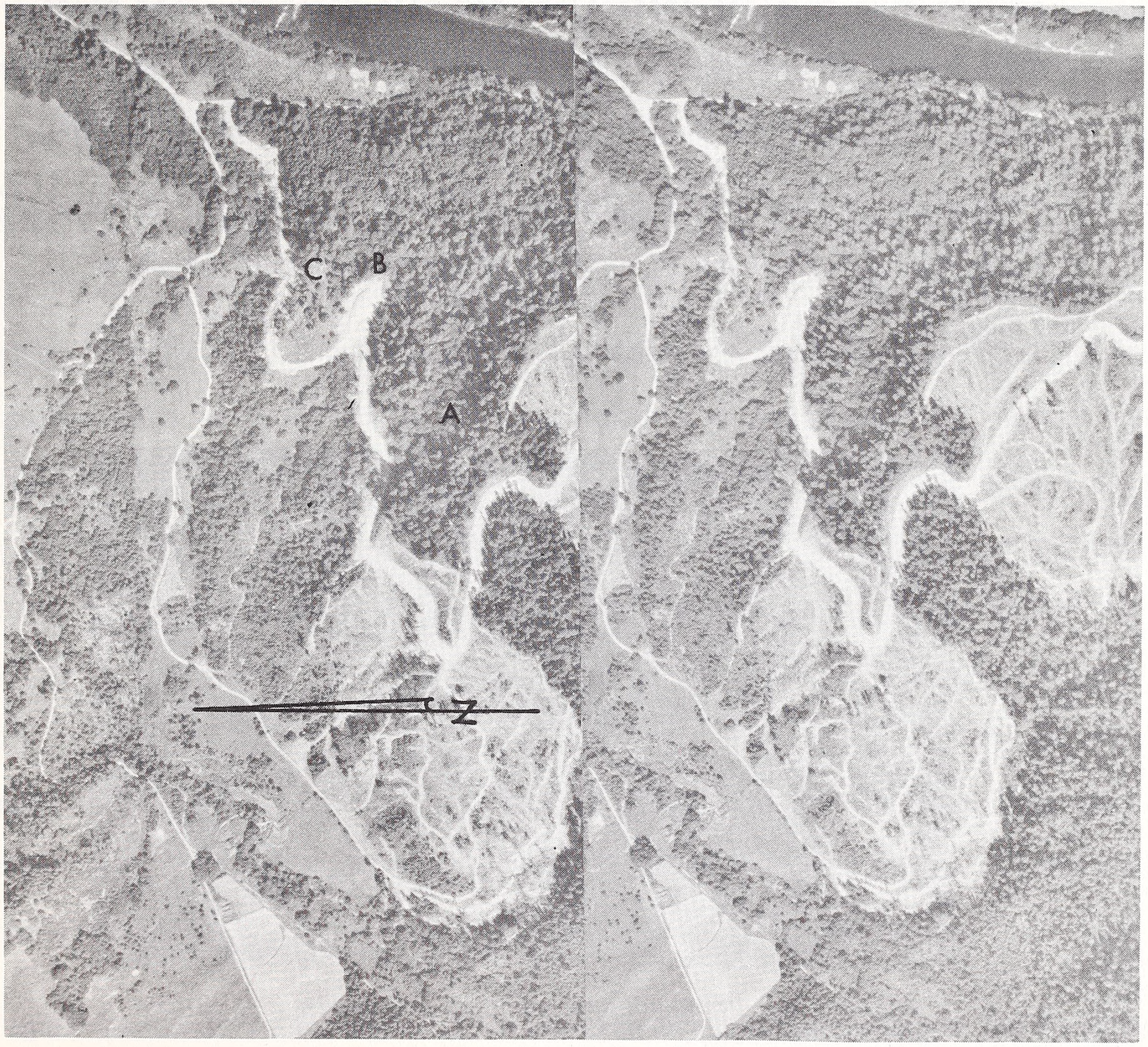

Figure 72. This is a stereogram of a road which was built through a large, old slump in the Yamhill formation. Point A is at the base of the main scarp. The light-colored area below point B is a disposal site for material from slumps into the road, mostly from point C. Ground water levels are high from point A through B to C. Sag ponds and water-filled depressions are numerous. Ditches connecting sag ponds to the road ditch northwest of point A have improved drainage of surface water and ground water. Ditches were deepened around the disposal site at B and extra culverts were installed to remove water and stabilize these slopes.

Special road design and construction techniques for this type of terrain may include the following:

Drainage ditches. Every effort should be made to improve drainage, both surface and subsurface, since ground water is the major factor contributing to slope instability for this material. Sag ponds and bogs should be drained by ditches excavated by tractor or by ditching powder, provided the explosion will not trigger a slope failure. Sag ponds and depressions at point A in Figure 72 were connected to the road ditch by a series of tractor excavated ditches as shown in Figure 73.

Figure 73. Ditches can be used to drain sag ponds and depressions.

Extra culverts. Extra culverts should be used to prevent water from ponding above the road and saturating the road prism and adjacent slopes. The light-colored area at B in Figure 72 is a disposal site for debris from slumps along the road from point C to the sharp curve. This

disposal site hindered the movement of surface water from the ponds and bogs at B. Ditches were deepened and extra culverts were installed on either side of the disposal site to conduct water more rapidly out of the area and across the road.

Good road ditches. Road ditches should be carefully graded to provide plenty of fall to keep water moving, and a special effort should be made to keep ditches and culverts clean following construction.

4. Remnants of Sedimentary Material on Steep Ridges of Igneous Rock

The fourth type of special slope stability problem in bedded sediments is caused by remnants of sandstone adjoining ridges of igneous rock, usually diorite. Igneous rock has intruded the bedded sedimentary material and erosion has removed all but scattered patches of this sedimentary material. Portions of the Lobster Creek Valley (southwest of Alsea) have this type of situation. As a general rule, any contact zone between sedimentary material and igneous material is likely to have slope stability problems. The igneous rock may have caused fracturing and partial metamorphosis of the sedimentary rock at the time of intrusion. Also, water is usually abundant at the contact zone and the sedimentary rock may be deeply weathered because the igneous material is relatively impermeable compared to the sediments.

Figure 74 shows a stereogram of a portion of Prairie Peak and the East Fork of Lobster Creek. The road parallels the sandstone-diorite contact except at the large point at A, the small ridgenose at B, and the large spur ridge at C. The contact zone is exposed at D. Note the alder which outlines the contact zone at B. Figure 75 shows this indicator of ground water accumulation. The large spur ridge at C may be relatively stable because of the large mass of

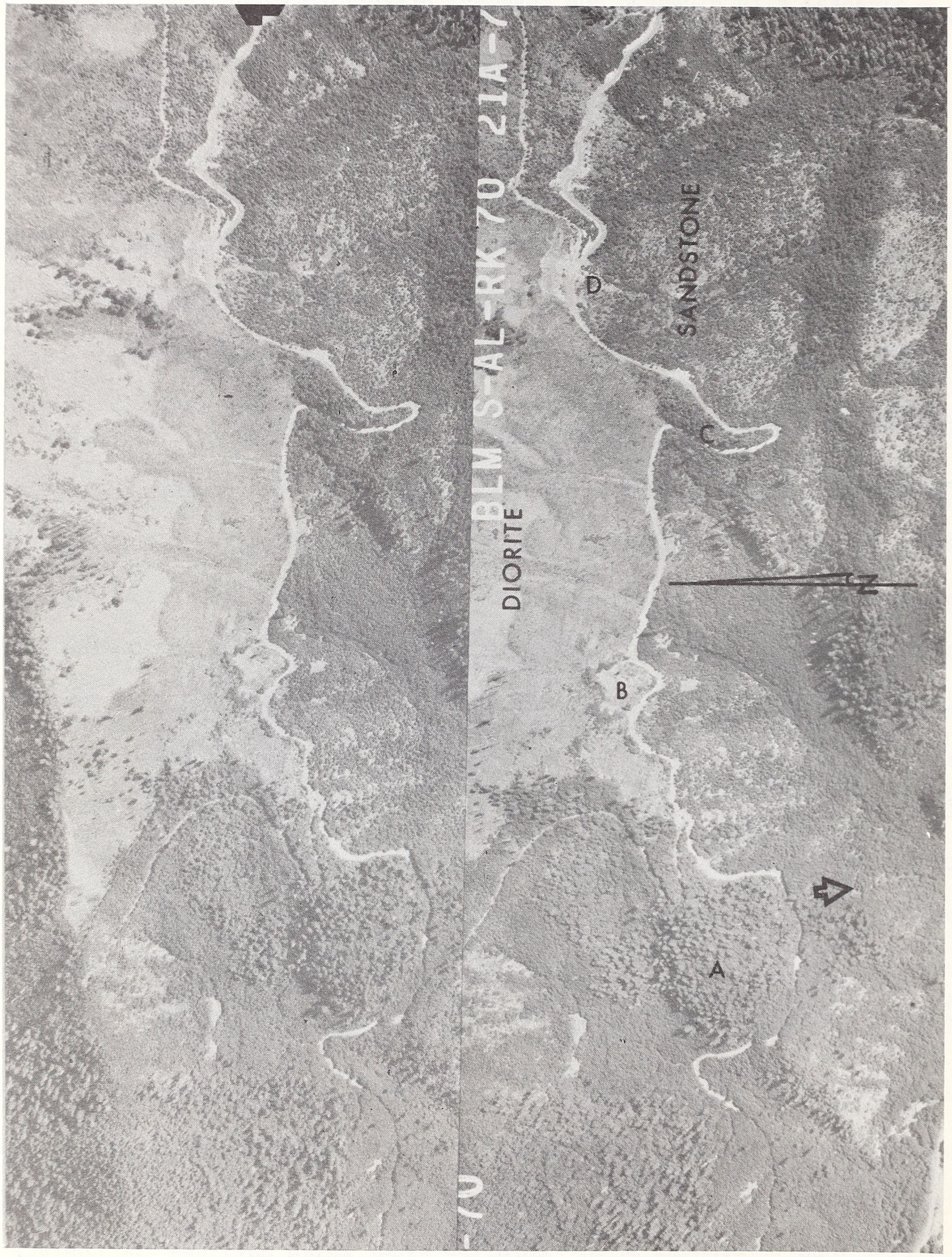

Figure 74. This stereogram shows a contact between diorite and sandstone. The road generally parallels the contact except at A, B, and C. The arrow locates a debris avalanche which occurred after these photos were taken. Ground water accumulation is indicated by the vegetation to the left of B. The contact zone is exposed at D.

material involved, and stability problems may be confined to the immediate contact zone (Figure 76). The arrow above A indicates the location of a debris avalanche which occurred since these photos were taken.

Figure 75. Sandstone ridgenoses on a slope of igneous rock.

Figure 76. Contact zone between sandstone (l.) and igneous rock (r.).

Special road location techniques for this type of slope stability problem include:

Attention to contact zone. Examine the terrain carefully on the ground and on aerial photos to determine if the mass of sandstone is large or small relative to the igneous rock mass. If the sandstone is in the form of a relatively large spur ridge, then the contact zone deserves special attention. The contact zone should be crossed as high as possible where ground water accumulation will be at a minimum. Elsewhere on the ridge of sandstone the stability problems will be the same as for sandstone Type I or Type II.

Consider alternate location. If the remnant of sandstone is relatively small, such as a ridgenose, then the entire mass of sandstone should be considered to be unstable and the road should be located above this material in the more stable igneous rock.

Design and construction techniques to be considered are as follows:

Avoid high embankment. The sedimentary rock in the contact zone is likely to be fractured and may be somewhat metamorphosed as a result of the intrusion of igneous rock. In addition, the accumulation of ground water is likely to have caused extensive weathering of this material. The road cut height at the ditch line should be kept as low as possible through this zone. Support by riprap rock may be necessary if the cut embankment must be high.

Good drainage. It is good practice to put a culvert at the contact zone with good gradient on the ditches to keep the contact zone well drained. Other drainage measures, such as drain tile or perforated pipe, may be necessary to control ground water.

Igneous Rocks (except Granitoid Rocks)

Slope stability problems of the intrusive igneous rocks (gabbro and diorite) usually concern contacts with sedimentary rocks, and these were discussed under Bedded Sediments, Subsection 4, "Remnants of Sedimentary Material on Steep Ridges of Igneous Rock". Slope stability problems in granitoid rocks will be discussed in a later section.

The extrusive igneous rocks (basalt and andesite) are often interbedded with pyroclastic rock (Figure 77); therefore, the slope stability problems of the extrusive igneous rocks and the pyroclastics overlap and will be considered together.

1. Extrusive Igneous Rocks (Basalt and Andesite)

Extrusive igneous rocks generally provide better road building material than

the bedded sediments. While the rock itself may be quite stable, the material may weather into deep soils with a potential for slumps and earthflows. The upper slopes are frequently steep with shallow soils while the lower slopes usually have thick soil mantles as a result of erosion from the upper slopes together with deep weathering. These igneous rocks are relatively impermeable and subsurface flow moves rapidly downslope. Much of this ground water appears as springs at the upslope side of benches that are common along the streams in this terrain. The remainder of the groundwater seeps through the deep soils to the streams. Road cuts often expose soil layers buried as a result of ancient slope failures and ground water may move laterally along these zones and appear as springs in the cut face after road construction (Figure 78). These local wet spots are a frequent source of small slumps.

Figure 77. Red breccia (bottom) overlain by basalt.

Figure 78. Arrow shows buried soil layer; pencils show springs.

Massive slumps are often found on the landscape, and sag ponds and hummocky terrain tend to keep the ground water levels high in these areas. Tipped and jackstrawed trees, together with hydrophytes, are the vegetative indicators of abundant ground water (Figure 79). Other features of concern are the steep slopes between the benches and the streams. Erosion of the base of these slopes results in a gradual steepening of the slope with a corresponding

increase in the potential for failure. Tension cracks are occasionally seen at the edge of these benches as the soil pulls apart.

The alternating layers of pyroclastic and extrusive rocks can create serious stability problems. For example, if basalt caps pyroclastic material, then the slumping of the soft pyroclastic rock can cause the collapse of large portions of the rigid basalt as support is removed. This situation is discussed in a later section on pyroclastic rocks. On the other hand, if pyroclastic rock overlies relatively impermeable basalt, then ground water will infiltrate the pyroclastic material and move laterally along the contact zone. Excavation for a roadway through this material may leave the contact zone halfway up the embankment (Figure 80). In this case the pyroclastics can slide onto the road, but the height of the contact zone creates an awkward situation for placing rock buttresses or perforated pipe. Geophysical exploration techniques should be used, if at all possible, during road location so that this situation can be avoided by changing the road location. If the road location cannot be changed, then rock buttresses and/or perforated pipe may be placed as the contact between these two materials is exposed during excavation.

Figure 79. Indicators of ground water.

Figure 80. Pyroclastics over basalt.

The "progressive" slope failure is another type of stability problem that is found frequently in deep soils on steep slopes in extrusive igneous material. This failure starts as an ordinary cut bank slump into a road. The removal of support causes failure of the next block of soil immediately upslope, and so forth, until there is a series of slumps one above the other that may extend to the top of the ridge (Figure 81). Ground water is usually abundant at these locations and engineers should be on the lookout for signs of an impending slope failure that could develop into a progressive slump.

Figure 81. A progressive slump is a series of slope failures that may extend to the ridge top.

Techniques for selecting the best road locations in this terrain include:

Use of photos. Examination of aerial photos to identify ancient slumps in advance of field surveys.

Adequate reconnaissance. Scout the terrain above and below the proposed road to locate springs, depressions, and bogs for estimates of extra drainage design.

Consider alternate location. If ground water appears to be a serious problem where a proposed road will cross a bench, then consider shifting the road onto the steeper slope immediately above the bench.

Geophysical equipment may be used to determine the difference in depth of soil at these alternate locations.

Avoid cracked soil. Avoid locating a road near portions of slopes with tension cracks. This is an obvious and reliable indicator of a failing slope.

Design and construction techniques which should be considered include:

Use special help. Utilization of every available specialist in BLM and other agencies together with the use of geophysical equipment to determine the type and magnitude of potential slope stability problems if it is necessary to build a road through a short section of unstable terrain.

Good drainage. If the potential stability problem involves ground water, then several remedial measures may be considered in addition to drainage of surface water:

Horizontal drains. Perforated plastic pipe installed in road cuts and fills may be required to control ground water.

Interceptor drain. Zones of ground water in road cuts which are too extensive to be handled by perforated plastic pipe augered into the road cut may be dried up by an interceptor drain installed under the ditch.

Embankment support. Potential slumps in the road cut may require support in the form of a rock buttress. Rock buttresses are especially effective in preventing progressive slumps.

2. Pyroclastic Rocks

The pyroclastics include 1) tuffs derived from volcanic ash, and 2) breccias, which are coarser textured and contain angular blocks of relatively hard material. Tuff and many of the breccias weather rapidly to clay and this characteristic makes the location of pyroclastic materials particularly important in the construction of stable roads. Tuffs and breccias may occur in isolated pockets, in relatively extensive deposits, or as layers sandwiched between layers of extrusive igneous rock.

Tuffs and breccias can come in a wide variety of colors which range from dark reddish-purple through light yellow to green (Figure 82). While all tuffs and breccias have marginal stability, the green variety is notoriously unstable. Soil and rock colors seem to provide a local field guide for prediction of the clay group and the relative landscape stability. Research by Paeth, et al., has shown that soils with montmorillonite clays have 2.5Y and 10YR color hues and have been derived from greenish rock. Relatively stable soils with 7.5YR hue have been derived from yellowish and reddish rock.

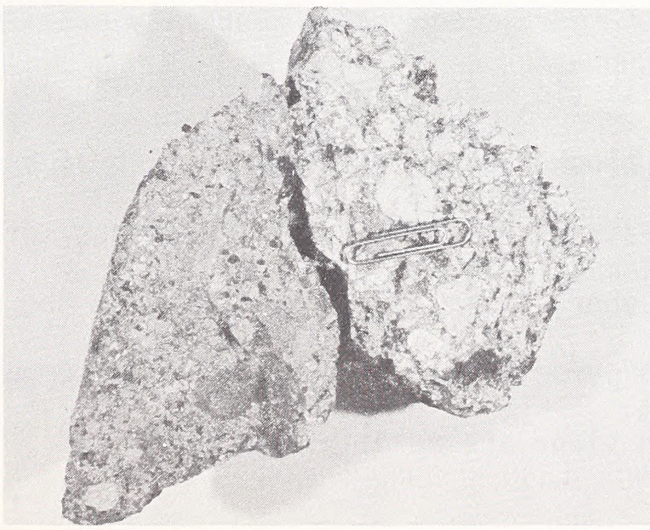

Figure 82. The color of pyroclastic materials may range from light green to dark reddish-purple.

The relationship between slope failures and pyroclastic material is summarized by Dyrness in a Forest Service study of mass soil movements in the H. J. Andrews Experimental Forest (on the west slope of the Cascades).

> "In the western Cascades, it has been observed that mass soil movements occur much more frequently in areas of pyroclastic rocks (tuffs and breccias) than in areas where the bedrock is comprised of basalt or andesite. It has also been noted elsewhere that greenish tuffs and breccias are more unstable than their reddish counterparts ..... About 94 percent of the events [mass soil movements] occurred in areas with a tuff and/or breccia substratum, even though only 37 percent of the total area is made up of these rocks. Moreover, 64 percent of the mass movements were on greenish tuffs and breccias which make up only 8 percent of the total area--clearly indicating the unstable nature of these materials. Although about 63 percent of the area is underlain by basalt and andesite material, only 6.4 percent of the mass movement events occurred there."

Unfortunately, there are no known techniques for locating pockets of green tuffs and breccias within a general region of pyroclastic material. Therefore, engineers and foresters should be alert to the exposure of this material during road excavation and be prepared to require drainage, riprap, or compaction as needed.

The various kinds of terrain and slope stability problems that may occur in igneous rocks and pyroclastic material are described in the following illustrations. Figure 83 is a block diagram of an area north of Brice Creek (a tributary of the Row River southeast of Disston) which is composed of layers of basalt and tuff. Note how the steeper slopes are associated with the harder basalt and the more gentle slopes with pyroclastics. Figure 84 is a topographic map of this area and the changes in slope are readily apparent.

Figure 85 is a stereogram of a portion of upper Thomas Creek (a tributary of the South Santiam River southeast of Mill City); this area has a thick layer

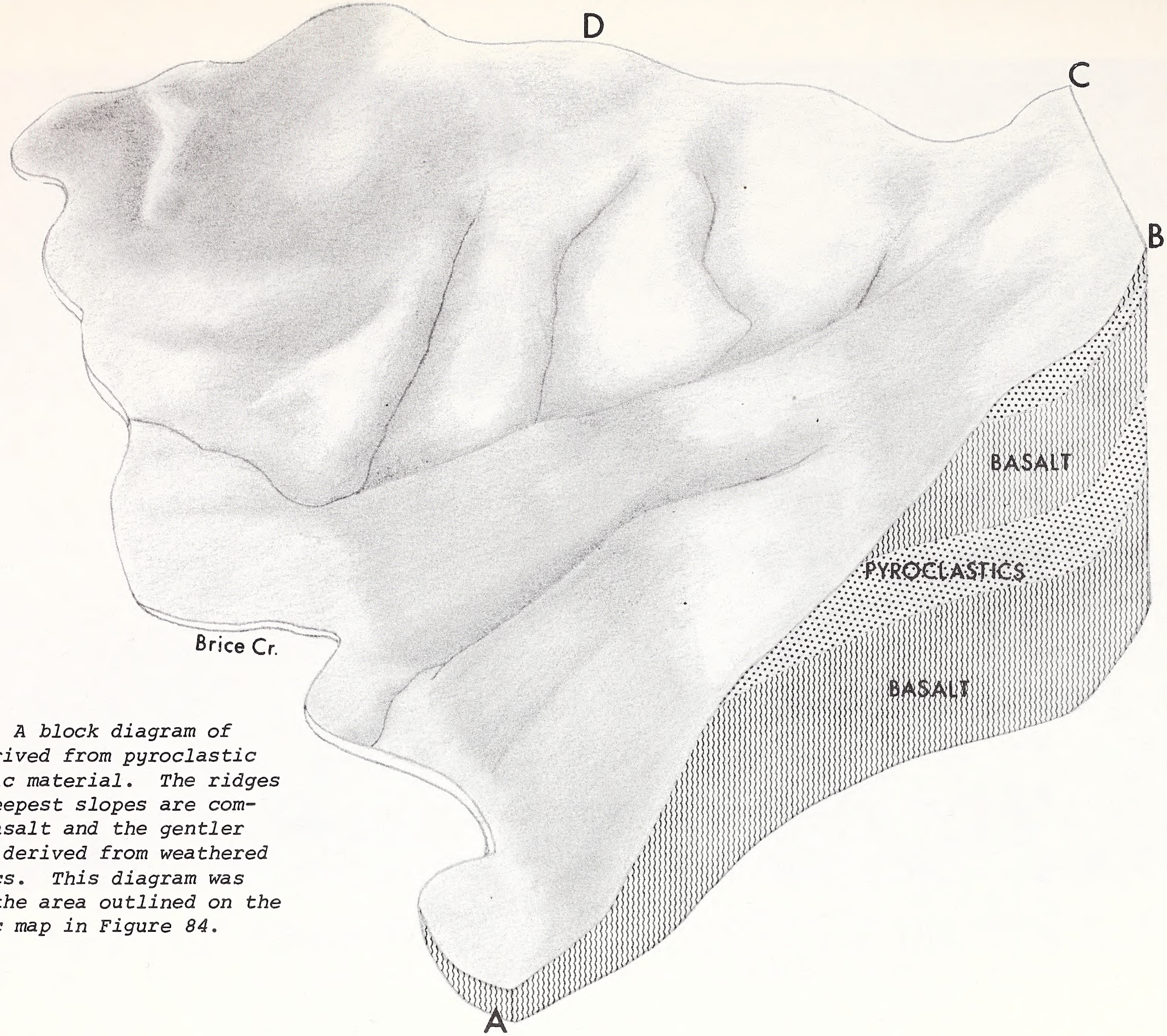

Figure 83. A block diagram of terrain derived from pyroclastic and basaltic material. The ridges and the steepest slopes are composed of basalt and the gentler slopes are derived from weathered pyroclastics. This diagram was made from the area outlined on the topographic map in Figure 84.

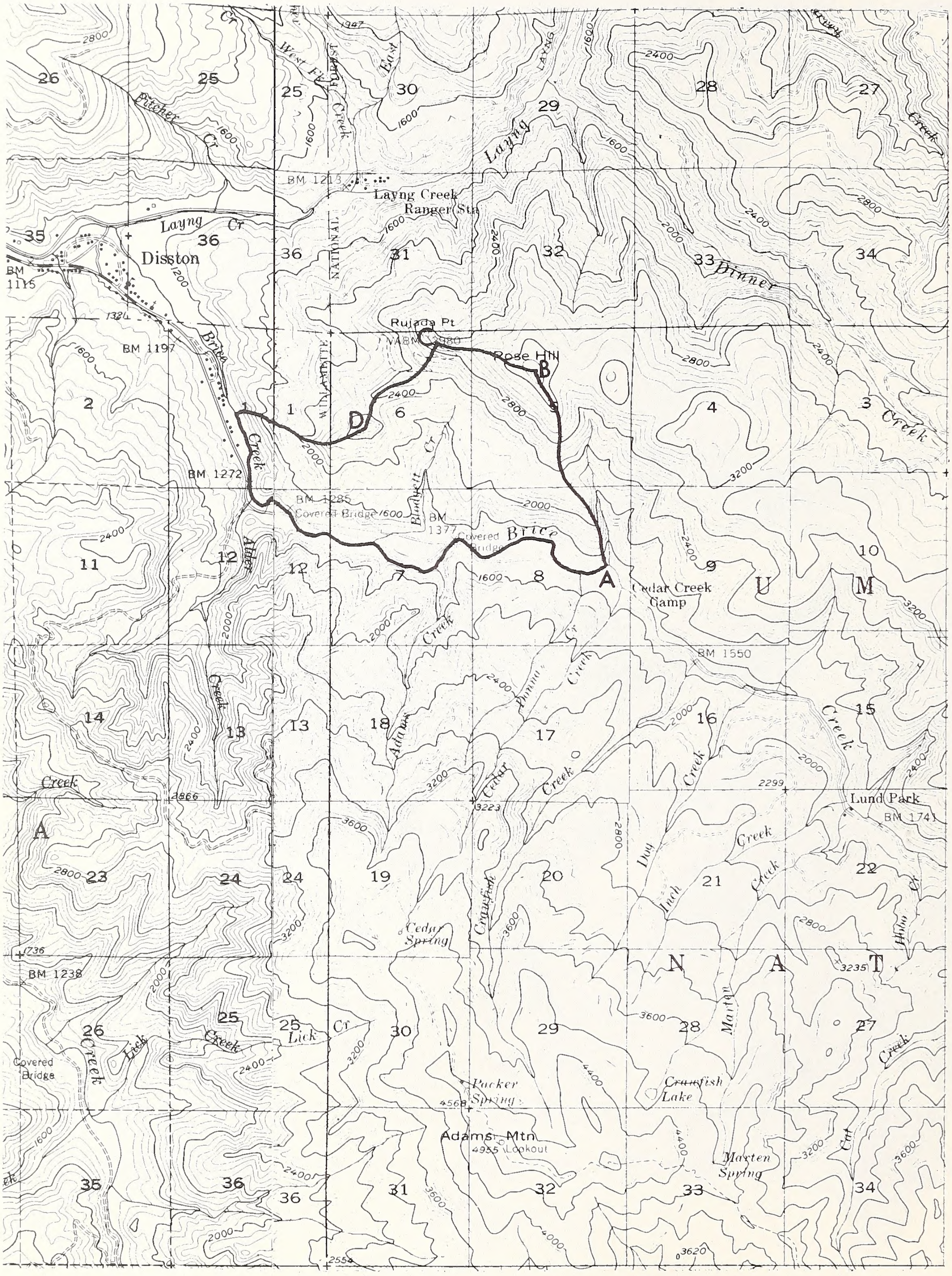

Figure 84. A topographic map of terrain derived from basalt and pyro-clastics. The outlined area was used to develop the block diagram on Figure 83; points A to D are used for orientation. Note the many small drainages, the alternating steep and gentle slopes which are typical of this terrain. Slumps are the most common type of slope failure.

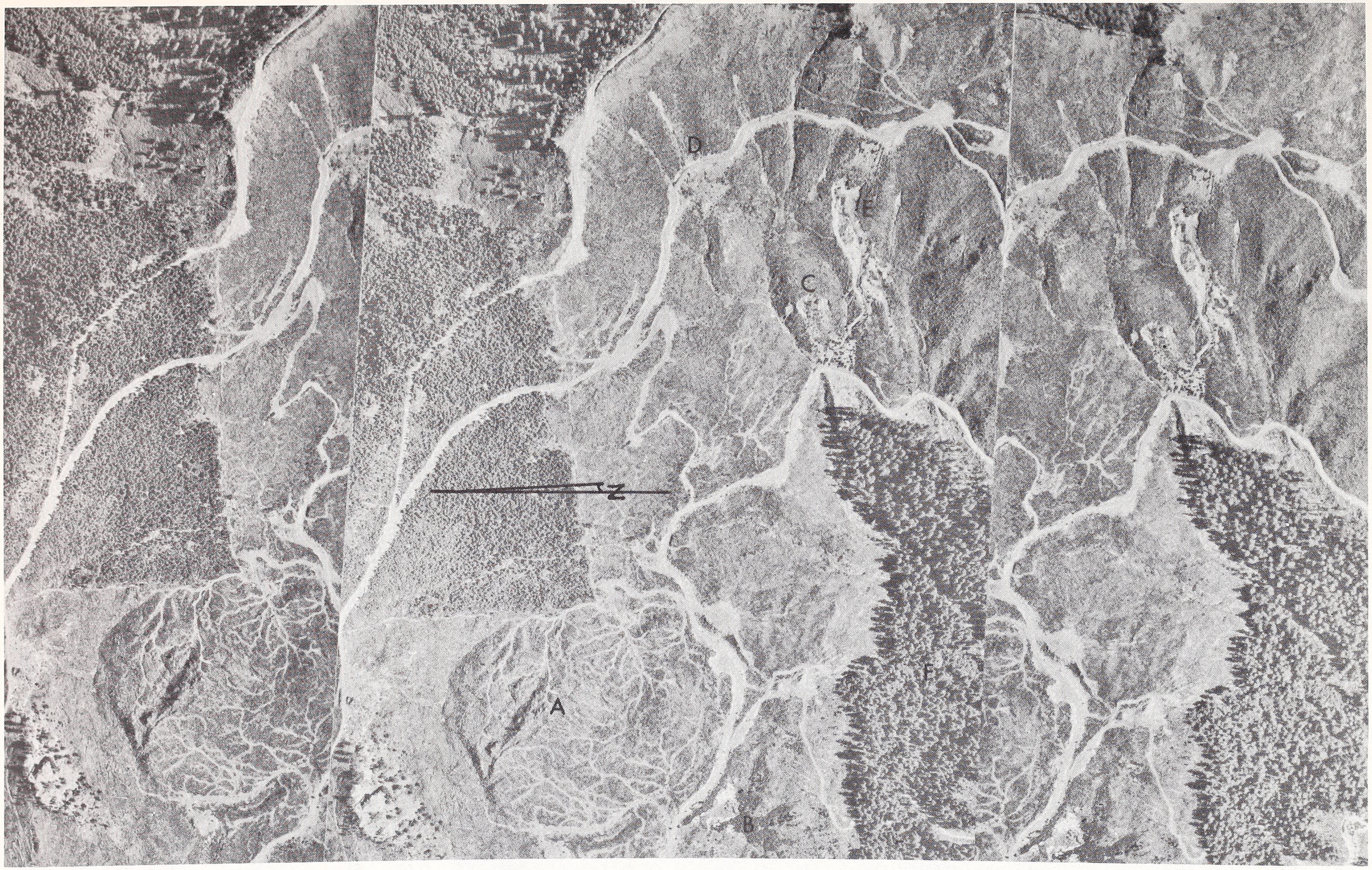

Figure 85. A stereogram of terrain developed from pyroclastics and capped by harder extrusive rock. The large, old slump at A appears to be covered with large pieces of cap rock. Other slumps, old and new, are found at points B to E. Note the hummocky landscape and the presence of hydrophytes at point F.

of pyroclastics capped by extrusive rock. Note the large, circular mass that appears to have slumped away from the higher ridges. There appear to be remnants of the harder cap rock at the summit of the slump mass (point A). There are many other smaller slumps that have created the benchy, hummocky terrain typical of unstable portions of pyroclastic material. There are large slumps, old and new, at B, C, and D, and smaller slope failures near D and E. Note how many of these failures originate in clearcut areas and are not associated with roads. The mature timber in the lower part of the basin contains tipped and leaning trees. Note the large clumps of alder, a locally defined hydrophyte, in the lower drainage at F.

The Lost Creek drainage is a tributary of the Middle Fork of the Willamette River, south of the Lookout Point Dam. This area also contains pyroclastic rocks interbedded between layers of andesite. Figure 86 is a stereogram that shows outcroppings of the harder rocks from point A around the spur ridge to B. The pyroclastics have slumped away from the ridge at A, and this has left the slump bench at C. The sample of tuff shown in Figure 13 was collected at C. The stream is removing the toe of the slump below C and is therefore gradually steepening the slope and creating an opportunity for more slope movement. The small basin between A and C collects water during the winter rains; this saturates the soil and causes cut bank failures at C. Figure 50 shows a portion of the rock riprap blanket that was designed by the Eugene District of the Bureau of Land Management to support this embankment.

Whitcomb Creek, that flows into Green Peter Reservoir on the Middle Santiam River, is an excellent example of unstable terrain associated with pyroclastic rock. Figure 87 is a stereogram that shows an old slump at A. A depression can be seen at the base of the scarp above and to the left of point A. Whitcomb

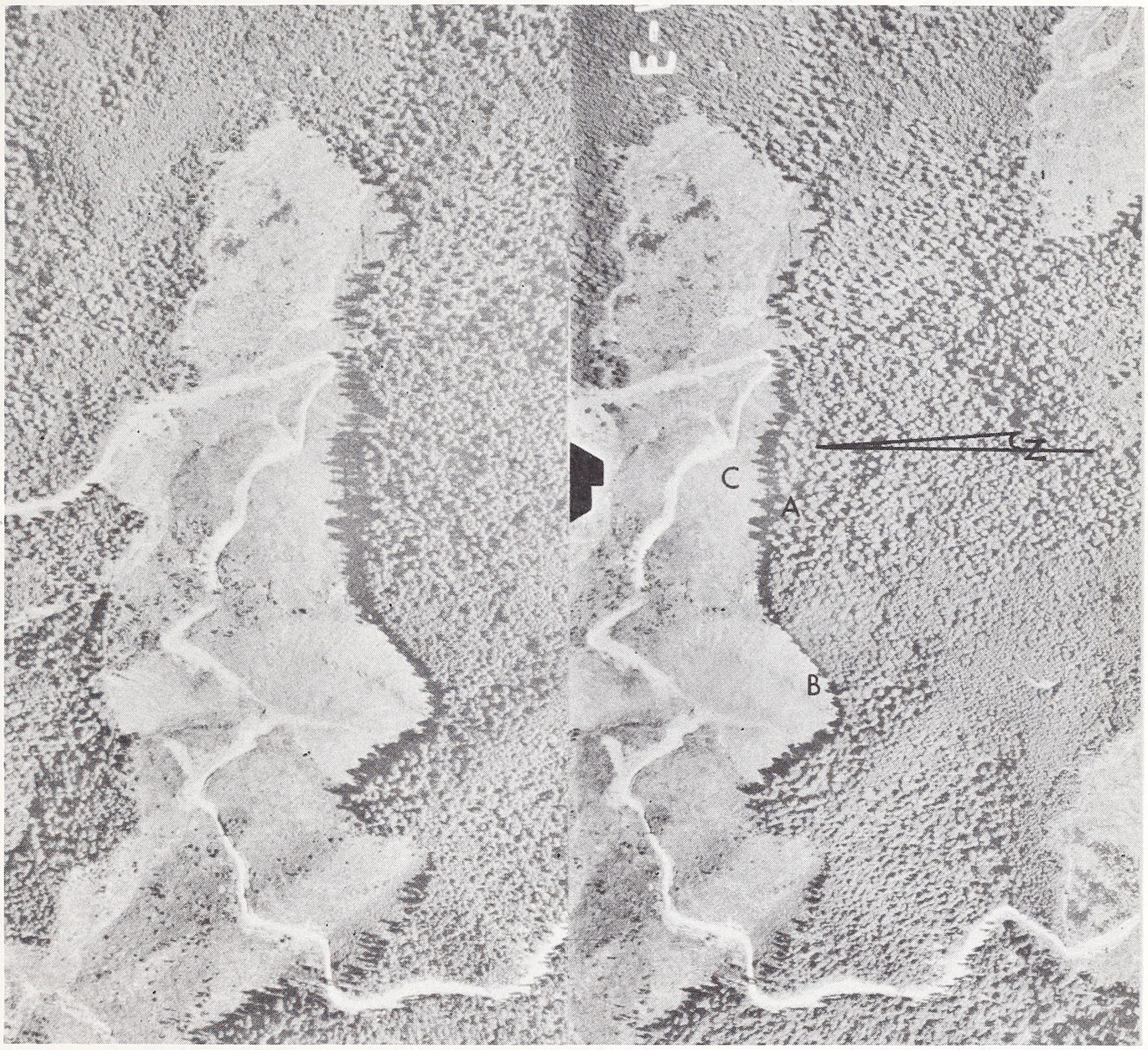

Figure 86. A layer of hard, extrusive rock, which forms cliffs from point A to point B, overlies softer pyroclastic rock. The softer material has slumped to form the gentle slope at point C. Winter rains saturate this slope and lead to cut bank failures at C. The rock riprap blanket shown in Figure 50 was designed to support the embankment at point C.

Figure 87. This stereogram shows unstable terrain derived from pyroclastic rock; there is evidence of active soil movement over the entire photo. An old slump is shown at point A and the dashed line outlines a new slump. Figure 88 shows a ground photo of this slump.

Creek has steepened the slope below this old slump and excavation for the road has removed even more support. This basin failed by slumping after these phots were taken and debris flowed into the creek. The approximate boundary of the new slump is shown on the stereogram. Damage to Whitcomb Creek from the debris flow down the channel was reported to be severe. Figure 88 shows a portion of the new slump and the presence of ground water at the head of the slump is shown by the dark stain on the exposed bedrock.

Figure 88. Ground photo of the new slump outlined in Figure 87. The arrow indicates ground water seeping from the face of the scarp.

Location of roads in pyroclastic material should include the following techniques:

> <u>Adequate reconnaissance</u>. Thoroughly scout terrain that has old slumps and hummocks to locate and avoid those areas with acute slope stability problems.
>
> <u>Consider ridges</u>. A ridgetop location should be considered where the road must traverse areas with a high potential for slope failure or where measures for slope stabilization (drainage, rock buttresses, etc.) would be prohibitively expensive.

Use benches. Benches on hummocky terrain may provide a relatively stable location provided the road width is reduced so that cut bank height will be an absolute minimum.

Avoid cracked soil. In all cases, avoid slopes with tension cracks, cat steps, and small scarps. These indicate that the slope is actively failing and that there is a poor chance to construct a successful road.

Consider alternate locations. Bogs and swales or other areas with indications of high ground water should be avoided. If it is necessary to cross these areas, scout the surrounding terrain to evaluate the chances of stabilizing the road by drainage or other remedial measures.

Design and construction techniques should be aimed at minimizing the removal of slope support by road excavation and maximizing slope stability through improved drainage.

Avoid overconstruction. Road design and construction through relatively stable pyroclastics should avoid overconstruction of the road so that slope instability will not be increased.

Avoid local unstable spots. Local areas of marginal stability in material that is otherwise relatively stable may only require a change in grade and/or alignment to keep road width and cut bank height to a minimum.

Consider endhauling. Excavated material may need to be endhauled if sidecast will overload the slopes below the road.

Use special stabilization techniques. Short sections of unstable ground may require the following remedial measures, either singly or in combination: single lane road, perforated plastic pipe augered into the slope, rock buttress for bank support, perforated pipe under the road ditch, and drainage of sag-ponds and swales.

Special attention to fills. Deep fills in areas of marginal stability should be avoided. Compaction of all deep fills is good practice.

Granitoid Rocks

Granitoid rock often weathers to a coarse-textured soil that may be low in clay if erosion is rapid. Those soils that develop in place for long periods may have a clay content of as much as 25 percent or more and may be relatively stable. Those soils that are low in clay have a single-grained structure with little cohesive strength that causes them to be easily eroded (Figures 89 and 90). It is these coarse-grained granitic soils that will be considered here.

Figure 89. This shows the steep, sharply dissected slopes which are typical of granitic material.

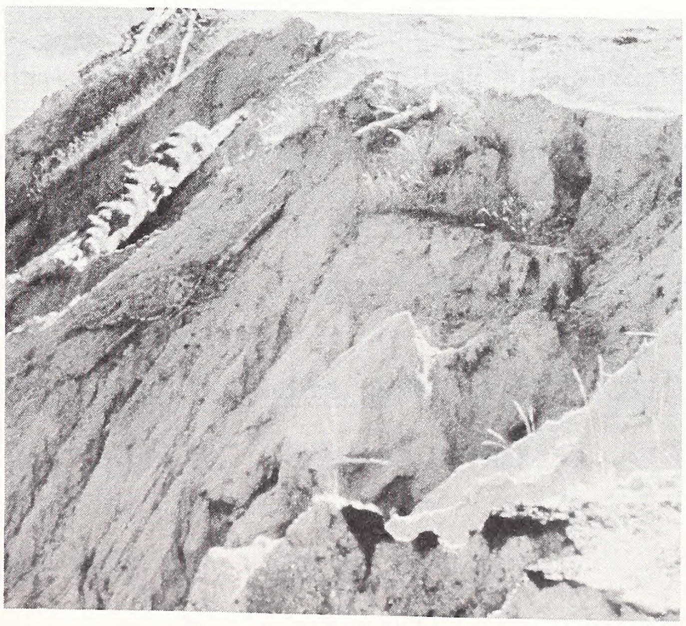

Figure 90. Granitic soils tend to be coarse-grained and very erodible as shown here.

The nature of the topography that is typical of granitoid bedrock is shown in the block diagram of Figure 91. This area was taken from the East Fork of Stouts Creek, a tributary of the South Umpqua River south of Milo. Note the steep, highly dissected slopes and the sharp ridges in the block diagram and the characteristic pattern of the contour lines on the topographic map (Figure 92).

Slopes over 70 percent are considered to be extremely unstable. Slope failures range from very shallow debris avalanches and flows to massive slump failures of road fills. Good drainage of road fills is vital as the coarser material depends almost entirely on frictional resistance to sliding for slope stability. Studies by the Forest Service on the Idaho Batholith north of Boise (as reported by Bailey) shows that 96 percent of the road failures occurred on slopes of 57 percent or greater. All but two of these failures were on fill slopes and 73 percent occurred in a stream channel or draw. Observations of fill failures in this material show that the failure of one road fill will often result in successive failures of other roads farther down the same channel as a result of debris flows.

Much of the following material on location, design, and construction of roads in granitoid rock was developed by the Roseburg District of the Bureau of Land Management and by the Forest Service as reported by Bailey. Road location techniques include:

> <u>Avoid steep slopes</u>. Locate roads on slopes with a gradient less than 50 percent. Ridgetop road locations are preferred.
>
> <u>Attention to grade and alignment</u>. Roll the grade to avoid long, steep side slopes. Do not devote so much attention to alignment that the road does not conform closely enough to the topography.

Figure 91. This block diagram of terrain developed from granitoid rock shows the steep slopes, sharp ridges, and sharply dissected slopes that are characteristic of this material. Figure 92 shows the topographic map from which this diagram was developed. Points A, B, and C may be used for orientation.

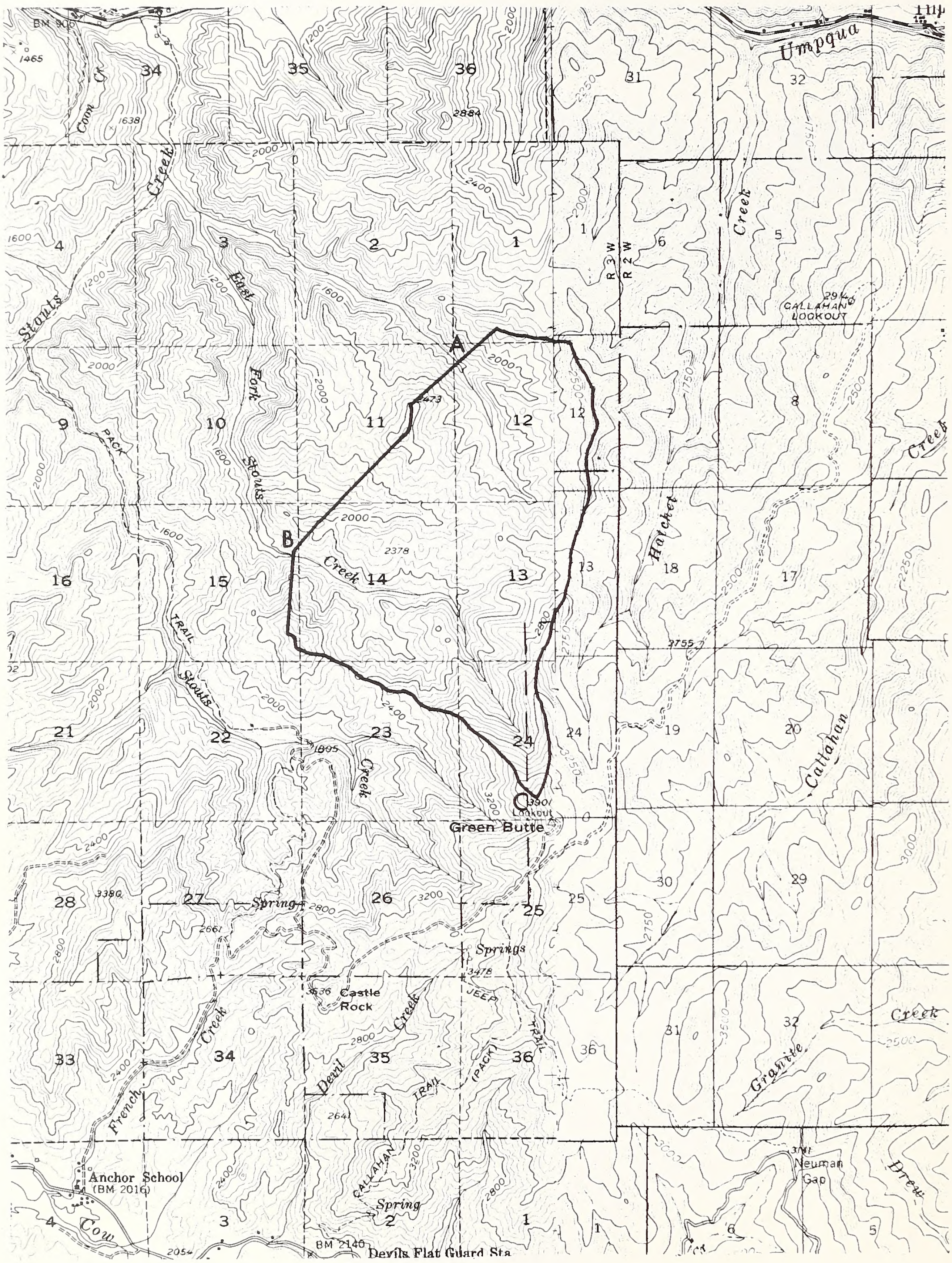

Figure 92. This topographic map was used to develop the block diagram on Figure 91. Points A, B, and C may be used for orientation. The drainage pattern is characteristic of these steep, easily eroded slopes. Debris avalanches are most common on steep slopes, but slumps may occur in deeply weathered material.

Avoid narrow stream bottoms. Avoid road locations at the bottom of narrow canyons that will require excavation of support from the base of long slopes.

Design and construction techniques that should be considered include:

Narrow road width. Keep the road width narrow; mainline roads may have 14 foot subgrade and spur roads may be 12 feet.

Minimize earth work. Sixty-foot radius curves may be necessary to keep earth-moving to a minimum.

Full bench on steep slopes. Use full bench construction whenever side slopes are 65 percent or greater.

Avoid trash in fills. Do not allow logs and debris to be incorporated into fills.

Compaction. Compact fills to accepted engineering standards consistent with design standards and material properties.

Culvert spacing. Design for close culvert spacing to get water out of the ditch before it builds significant erosive power. Frequent culverts will also assure that a large quantity of drainage water will not be discharged onto the lower slope at any one time.

Culvert alignment. Culverts should be skewed with respect to the ditch line so that water does not have to turn 90^{o} to enter the culvert. Also, consider rock headwalls at the culvert entrance to prevent water from by-passing the culvert.

Metamorphic Rocks

BLM soil scientists in southwestern Oregon indicate that slope stability problems in the metamorphic materials fall into four categories: 1) blocks of deep, red, clayey soils adjacent to drainages or on steep hillsides, 2) isolated pockets of unconsolidated rock and soil (called colluvium), 3) deeply weathered and easily eroded schists along the East Fork of Evans Creek, and 4) slope stability problems associated with igneous and pyroclastic rocks; the stability problems of igneous and pyroclastic rocks were discussed in section B.

Many centuries of soil development have created some very productive red, clayey soils in many areas of southwestern Oregon. These soils were originally developed on gentle to moderate slopes but geologic uplift and subsequent drainage development have left many blocks of this soil on steep hillsides. Downcutting by streams has left some of these soils in a condition of precarious stability. Excavation for roads may remove enough support from these blocks to cause slumps during the winter when the soils become saturated. Figure 93 shows a very large slump along the Galice Road northwest of Grants Pass. The magnitude of slope failures such as this makes slope stabilization an impossible task. The best method to prevent these types of slope failures is to avoid locating roads under or through blocks of clayey soils on steep hillsides. These soils are designated as the 380, 381 and 382 series. The soil depths range from 20" to over 40" and the texture may vary from skeletal red clays (greater than 35 percent coarse fragments) to red clays. The presence of these soils along a proposed road location may be determined from soil maps or by digging down to mineral soil to look for the characteristic red color. Slope instability may be indicated by tipped trees, tension cracks, cat steps, etc.

The isolated pockets of colluvium present a different slope stability problem. One theory for the development of these pockets of colluvium is that they represent ancient valleys or slump escarpments which were filled in by soil and rock. Geologic uplift and/or faulting may have lifted masses of material to higher elevations and subsequent development of entirely new drainages has carved valleys which may be at sharp angles to the ancient channels. Road excavation may uncover these deposits of colluvium high on the hillside. This unconsolidated material is usually quite unstable and slumps at these locations are common. Unfortunately, the present-day hillslope offers no clues for locating pockets of colluvium. This material is included in the 370 soil series which is described as a brown, gravelly loam over 40" deep. Engineers should be prepared to place rock riprap against the embankment at these locations to provide the support which was removed by road excavation.

The schists along the East Fork of Evans Creek, northwest of Medford, present some severe slope stability problems. This material is found near

masses of granitoid intrusions, which probably provided the conditions for metamorphism. This schist is pictured in Figure 17 and this black-and-white rock weathers rapidly to a gray-colored cohesionless material which resembles coarse-to-fine sand. In fact, it has been reported by personnel of the Medford District that an apparently solid rock from a road cut weathered to a pile of "sand" in just one winter. Figure 94 shows the rockfalls which are typical of deep cuts in this material; frost action is particularly effective in loosening the face of road cuts. Control of ground water is essential with the Evans Creek schist because of the cohesionless nature of the soils. Very wet areas may exhibit the slumpy, hummocky terrain of some of the siltstone material; note the tipped tree in the center background of Figure 94. Figure 95 shows a sagging road fill and Figure 96 indicates a common cause of road fill failures, both in the schists and in granitoid rocks--impeded ditch drainage as a result of rapidly eroding cut banks. Poor ditch drainage allows water to infiltrate the road prism instead of being carried away. Discharge from culverts can easily erode these soils if the water is allowed to fall on an unprotected fill, as shown in Figure 97. Techniques for road location and construction in the steeper portions of Evans Creek schist are similar to those for the granitoid rocks. For the slumpy, hummocky terrain in the Evans Creek schist use the road location and construction techniques which were suggested for siltstone material under Bedded Sediments, subsection 3, "Deep Soils Derived from Siltstone", with particular attention to the need for extra culverts.

Figure 94. Rockfalls in deeply weathered schist. Note tipped tree.

Figure 95. Cracked and sagging road fill in schist.

Figure 96. Small slumps cause impeded ditch drainage.

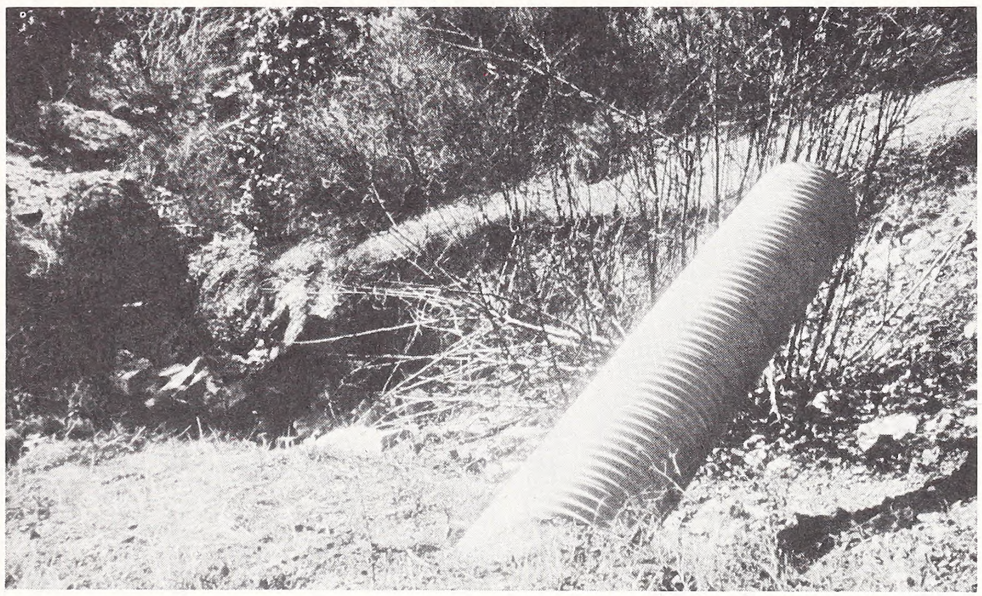

Figure 97. Weathered schist is easily eroded. Culverts should not discharge water onto unprotected fills.

Serpentine

Serpentine is a material whose particular slope stability problems vary from the relative dry (30" to 50" annual precipitation) interior portions of southern Oregon, to the wet (80" to over 100" annual precipitation) coastal climate of extreme southwestern Oregon. In the drier climates, the slope stability problems appear to be those associated with any fault zone, as reported earlier. Soil scientists report that crushed and fractured rock may extend from several hundred feet to 1/4 mile or more on each side of the serpentine intrusion. The terrain tends to exhibit a slumpy, hummocky appearance as a result of the weathering of serpentine to clay when ground water is present in these zones.

The presence of extensive areas of serpentine material may be indicated by vegetation composition and density that is characteristic of these areas. Serpentine and peridotite (from which serpentine is derived) contain an excess of magnesium. Only tolerant plants can grow on these soils when this mineral is present in quantities sufficient to be toxic to many plant species. The major coniferous species under these conditions are Jeffrey pine, with some western white pine and knobcone pine. Tolerant shrubs and forbs are pine-mat manzanita (*Arctostaphylos nevadensis*) and beargrass (*Xerophyllum tenax*). Figure 98 shows a typical hillside of serpentine soils in the drier zone that appears as an open woodland with a sparse growth of grasses and shrubs. Figure 99 is an aerial photo of a portion of Cow Creek, southwest of Riddle. The approximate boundary between the serpentine material and the Umpqua formation is shown as a dashed line. This delineation was made on the basis of the difference in density of vegetation.

Figure 98. Sparse stands of Jeffrey pine often indicate the presence of serpentine bedrock.

Serpentine material behaves somewhat differently in the wet coastal climate. There is enough rainfall to cause rapid weathering of exposed serpentine to a sticky clay--often referred to locally as a "blue clay" (Figure 100). Small outcroppings of serpentine occur in other geologic materials such as the Dothan formation where vegetative indicators of serpentine may only be a grassy hillside (Figure 101). These grassy openings often show tension cracks and cat steps. Rock riprap for support of the cut bank and control of drainage water may be the only slope stabilization techniques that are possible when roads traverse small areas with serpentine soils. Care should be taken to distinguish between small serpentine outcrops and exposures of thin beds of dark siltstone within the Otter Point formation, the Dothan formation, and other minor sedimentary formations along the southern coast. These beds of siltstone may be tilted to a nearly vertical position, they may be deeply weathered, and they often slump and flow into the roads. These beds may be covered with the same vegetation that is on the surrounding terrain, but the weathered siltstone does not have the high clay content of the weathered serpentine.

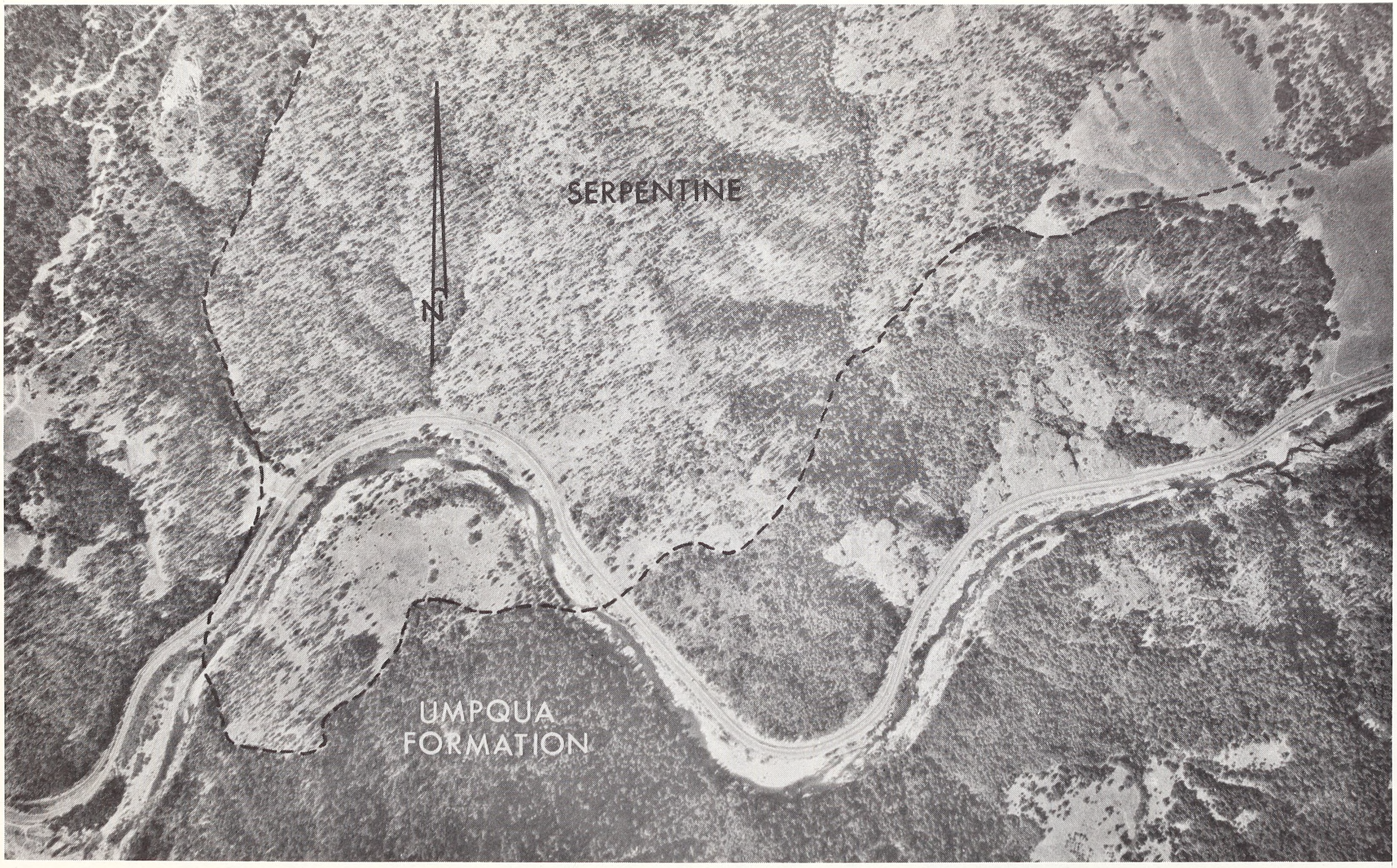

Figure 99. The approximate boundary between serpentine material and the Umpqua formation is shown by the dashed line. This determination is made principally on the basis of vegetation density. Timber on portions of the Umpqua formation have been harvested which accounts for a reduction in vegetation density, particularly in the northwest corner of the photo.

Figure 100. Serpentine often weathers to a sticky clay.

Figure 101. Grassy hillsides often indicate small serpentine outcrops.

Some techniques for road location in serpentine include:

Use maps and photos. Examine geologic maps and aerial photos to locate serpentine outcrops.

Indicators of serpentine. Become familiar with the vegetative indicators of serpentine soils. This should include field identification of key plants and also gross delineation on aerial photos.

Alternate locations. Avoid road locations through basins with extensive areas of serpentine material. It may be impossible, technically or economically, to stabilize roads once they have been constructed through these basins.

Special information. Areas which appear to have thin outcrops of serpentine should be examined by specialists to estimate the degree of faulting and/or fracturing, the amount of weathered clayey material which is present, and the amount of ground water which is likely to be present in the winter.

Some construction techniques which should be considered in serpentine material are:

<u>Embankment support</u>. Be prepared to apply blankets of heavy riprap rock for slumping cut banks (Figure 102).

<u>Ground water drainage</u>. Be prepared to collect and dispose of ground water through extra drainage work as the magnitude of the ground water problems become evident as construction begins. This extra work may include perforated pipe in the cut bank (Figure 103).

Figure 102. Heavy riprap may be used to support slumping embankments in serpentine material.

Figure 103. Perforated pipe may be needed to remove ground water from embankments in serpentine material. Note the volume of water issuing from the pipe at the right of center.

MAINTENANCE

Proper road maintenance is an extremely important phase of constructing stable roads. Maintenance personnel should have the same understanding of basic geology and soil mechanics as the engineers who locate, design, and construct the roads. Maintenance personnel who are knowledgeable in these fields can avoid creating unstable conditions on slopes, and they can recognize symptoms of impending slope failures so that slope stabilization techniques can be initiated. Some of the elements of good road maintenance are discussed below.

Disposal of Debris from Slope Failures

Disposal of debris from avalanches or slumps that falls upon the road is a serious problem. Disposal sites which will safely support rock and soil may be a long distance from the slope failure. Nevertheless, such safe disposal sites should be sought out and used. Never take the expedient approach and dump soil, rocks, and debris into drainages or any other spot where this material will increase the potential for slope failure. Figure 104 shows the result of a debris avalanche in a steep headwall in Tyee sandstone. The rubble, which extends from the lower part of the photo to the road which circles the top of the headwall, is a result of disposal of debris from cut bank failures elsewhere along the road. In this case, the headwall is primed for another destructive debris avalanche -- all it needs is a series of heavy winter rains to raise the ground water level.

Symptoms of Active Slope Movement

Maintenance personnel (and also foresters and engineers) should be alert to the signs of impending slope failure or poor drainage, such as sagging of the

Figure 104. Rubble from road clearance has been deposited in this steep headwall. This increases the potential for another slide.

cut bank or fill, trees which begin to tip or lean, the appearance of new or accelerated ground water discharge from the cut bank, and standing water in ditches. Slope and road failures may be prevented if prompt action is taken to correct the cause of these symptoms of active slope movement.

Good Culvert Practice

Culvert outfall should not be discharged into fill slopes in a manner which can erode the slope or decrease slope stability through saturation of the fill.

This is particularly important in granitoid material. Discharge from culverts should be conducted to a stream channel, or other safe disposal area, by means of downspouts, half-rounds, or impervious aprons. If half-rounds are used, they should be bolted to the end of the culvert and firmly staked to the fill slope to prevent twisting. The energy of culvert discharge should be dissipated on rocks, or other suitable material, to kill the erosive power of the water. Culvert discharge should not be allowed to accumulate on lower slopes. Ditching may be necessary to prevent ponding and the possible creation of slope instability below the road.

Slope Protection

Raw slopes should be seeded as soon as practicable after road construction to reduce soil erosion. Road maintenance should do everything possible to encourage the establishment of vegetation on cuts and fills. It is important to leave the cut slopes as rough as possible in granitoid material to aid in rapid establishment of stabilizing vegetation.

SUMMARY

It is hoped that this guide has emphasized that construction of stable roads in western Oregon is a complex task that requires a background of knowledge from many fields. The construction and maintenance of stable roads will require many decisions, from the early planning stages through routine road maintenance, and each of these decisions must be based upon an understanding of the basic principles of geology and soil mechanics.

A realistic philosophy towards the construction of stable roads is given by Bailey:

> "It should be realized that not all landslides can be prevented. Probably, the exceptionally large landslides are primarily controlled by the rate of geologic erosion and are largely uninfluenced by activities of man, but smaller earth movements initiated by man's activities are, in turn, at least partially preventable or controllable by man. Included in this concept is the decline of the view of a landslide as an "act of God" and the growing realization that many landslides are initiated by "acts of man." Increasingly, the land manager is faced not only with the increased possibility of landslides, but also with greater economic losses and greater chances for injuries and deaths when landslides occur. In addition, he must necessarily be aware of the effect of management activities in unstable areas on the sustained yield of high quality water because of the increasing need for improved water management. Furthermore, he must consider the effect of management on landslide activity which tends to reduce the soil mantle. The importance of soil loss is apparent when its very slow recovery rate is considered."

Several principles for construction of stable roads in western Oregon should be re-emphasized here. The first principle is "an ounce of prevention is worth a pound of cure"; avoid unstable terrain if at all possible. Utilize geologic maps, aerial photos and careful on-the-ground scouting to locate potential slope failures. Second, be prepared to sacrifice alignment, road width, and road grade to avoid trouble spots. Third, if problem areas must be traversed,

be prepared to implement preventative measures during road construction. Fourth, maintenance activities should be geared to maintain or improve road stability. This will include keeping a close watch for symptoms of impending slope failure. Finally, for each activity concerned with the road system, such as road location, design, construction, and maintenance, utilize every opportunity to control water -- both surface water and ground water.

We believe that if the information which is found in this guide is applied to the problems of stable road construction in western Oregon, then the number of slope and road failures caused by "acts of man" can be reduced by as much as 50 percent as a practical goal.

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